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AN INTERGRATED STUDY OF EARTH RESOURCES
IN THE STATE OF CALIFORNIA
USING REMOTE SENSING TECHNIQUES

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A report of work done by scientists of 4 campuses of the University of California (Davis, Berkeley, Santa Barbara and Riverside) under NASA Grant NGL 05-003-404

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AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA USING REMOTE SENSING TECHNIQUES

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Chapter 1

INTRODUCTION

Robert N. Colwell

The material appearing in this Progress Report reflects our concentration on the preparation of procedural manuals that deal with applications of remote sensing to the inventory and management of natural resources.

In conformity with our NASA-approved plan we have arrived at either the final or the near-final iteration of our various procedural manuals that deal with applications of remote sensing to water resources. Now, as we are nearing the termination date for this grant we are concentrating our efforts on the preparation of procedural manuals that deal with applications of remote sensing to an area's entire "complex" of earth resources, including its vegetation, soils, geology and water resources.

These Procedural Manuals will continue to be subjected to user agency reaction. Furthermore, the finalized versions will be prepared: (1) in both abridged and unabridged versions, the latter providing much more complete step-wise descriptions and documentation than the former and (2) in degrees of aggregation ranging from a single aspect per manual to all aspects. We are completing, for example, three separate Procedural Manuals relative to aspects of water-supply estimation by remote sensing--those dealing, respectively, with snow areal extent, snow water content, and evapotranspiration. These in turn will be compiled (with suitable integration) into one manual dealing with the estimation of water supply. Finally the integrated water sup-

ply volume will be further integrated with similar Procedural Manuals dealing with one aspect or another of remote sensing in relation to the estimation of water demand. Thus, the rather sizable overall document will be for use of those concerned with all aspects of water resource management (both the supply and the demand aspects) while each of its various subdivisions, when made to stand alone, will better serve the needs of those concerned with only one limited aspect or another of this management problem.

A major part of the rationale for our having concentrated our remote sensing research on California's water resources for the past several years resides in the following facts:

(1) From the economic standpoint, water is the most important resource obtainable from California's vast wildland areas, i.e., from the areas in which, because of difficulty of access on the ground, remote sensing is most needed.

(2) Since the supply of water that is present in California's wildland areas tends to fluctuate far more from season-to-season and year-to-year than does the supply of the other resources found there, the importance of remote sensing as an aid to the making of frequent and periodic inventories (i.e., to the "monitoring") of California's water supply becomes even greater.

(3) Virtually all of California's most important industry, viz., agriculture, is very heavily dependent upon water. In fact, the water required to irrigate California's agricultural crops presently constitutes more than 80 percent of California's total water demand--the rest coming primarily from various industrial, commercial, and domestic uses. Furthermore just as the supply of this water can vary dramatically from season-

to-season and year-to-year, so can the demand for it. Consequently, in view of the vastness of California's agricultural lands, and the frequency with which the water resource manager needs current, accurate information on the water demands that are being imposed by those lands, remote sensing constitutes a means of great potential importance for the inventory and monitoring of water demand.

(4) Not only in California, but also in many other parts of the world, water is becoming an increasingly critical resource in relation to the economic well-being of mankind. It is probable that remote sensing techniques of the type which we have been developing for the inventory and monitoring of California's water resources could be applied, with only slight modification, to other parts of the world as well.

The approach that has just been described is being used as we broaden our studies so as to include the entire earth resource complex, area-by-area, in selected parts of California. With respect to the preparation of these more comprehensive Procedural Manuals, we frequently have discussions with various resource managers in California including (1) California's Regional Forester of the U. S. Forest Service; (2) the Supervisors of various U. S. National Forests in California; (3) their counterparts in California's State government; and (4) those concerned with resource management for representative county governments and private industrial groups. As a result of these discussions we are learning, area-by-area, and example by example that (1) in some instances it would be preferable from the intended user's standpoint for any given Procedural Manual to deal with remote sensing as applied to only a single

resource because the management objective, quite simply, is to obtain maximum production or benefit from that single resource, even at the expense of receiving reduced production or benefits from other resources that pervade the same area and (2) in other instances it would be preferable for the Procedural Manual to deal with remote sensing as applied to the inventory and management of multiple resources or, indeed, to the entire "resource complex". In instances of this second type the policy which the resource manager has been told to implement is one that recognizes the "tradeoffs" that necessarily result when efforts are made to favor one resource over another. Hence, he has the nontrivial task of managing the entire porperty that has been entrusted to him in such a way as to provide an optimum "mix" of resource products. It, therefore, will be our objective, as we produce this second type of remote sensing-oriented Procedural Manual, to present a step-wise procedure, complicated though it necessarily will be, for inventorying an area's entire resource complex.

Chapter 2

WATER SUPPLY STUDIES BY THE DAVIS CAMPUS GROUP

Co-Investigator: Ralph Algazi

Contributor: Minsoo Suk

Chapter 2

WATER SUPPLY STUDIES BY THE DAVIS CAMPUS GROUP

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Contributor: Minsoo Suk

(Explanatory Note by R. N. Colwell, Principal Investigator of the Integrated Study that is being performed under this grant):

Attention is invited to Special Study No. 3 in the present Progress Report entitled "Satellite Land Use Acquisition and Applications to Hydrologic Planning." That report was prepared by the long-time Co-Investigator from the Davis Campus for this NASA-funded, integrated study, (Dr. Ralph Algazi) and by his associate Dr. Minsoo Suk. Furthermore, the material contained in that Special Study is highly compatible with the emphasis that has been given during the past several years by all of our study participants relative to the remote sensing of California's water resources. Nevertheless, that material does not appear in this Progress Report as a complete chapter, even though the contributions from Algazi et al. have been so treated in the past. This change merely reflects the orderly transition that has been occurring during the past year (with NASA approval) as the Algazi team has been bringing to a close its studies as funded under this particular NASA grant, and transferring its remote sensing-related activities to follow-on programs under separate funding.

The change just described is regarded by all concerned parties, both within NASA and within the University of California, as a healthy transition. This is especially so because the newly directed efforts of the Algazi team are

brought about by their having been designated as participants in an Applications Systems Verification Test relative to uses that can be made of remote sensing in the estimation of water supply. Thus their re-directed efforts represent a logical step toward bringing about the acceptance by user agencies of certain kinds of remote sensing technology that have been developed, at least in part, by the Algazi group during their several years of participation in this grant.

It is for the reasons indicated above that (1) for the first time there is not a full chapter in this Progress Report detailing grant-funded activities of the Algazi group, and (2) there is nevertheless a substantial contribution from that group appearing in Chapter 7 of this report as Special Study No. 3.

As acknowledged on page 7-51, the Algazi material that comprises Special Study No. 3 was funded in part by our present NASA-funded "Integrated Study" grant No. 05-003-404.

Chapter 3

WATER SUPPLY STUDIES BY THE BERKELEY CAMPUS GROUP

Co-Investigator: Siamak Khorram

Scientific Collaborator: Edwin F. Katibah

Contributors: H. Gregory Smith
Agnis Kaugars
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Chapter 3

WATER SUPPLY STUDIES BY THE BERKELEY CAMPUS RSRP GROUP

Co-Investigator: Siamak Khorram
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3.000 INTRODUCTION

Most of the work that has been performed during the present reporting period by the Remote Sensing Research Program (RSRP) personnel at the Berkeley Campus has continued to deal with water supply studies. The focus of these studies is the development of remote sensing-aided procedures to provide cost-effective, timely, and satisfactorily accurate estimates of various important components of hydrologic models. Specifically, procedures are being developed for estimating the areal extent of snow, the water content of snow, the amount of solar radiation, and the loss of water to the atmosphere by evapotranspiration. The values obtained for these components by means of remote sensing will be used as inputs to each of the two state-of-the-art water yield forecast models currently being operated by the California Department of Water Resources (DWR). These are (1) the California Cooperative Snow Survey's (CCSS) model; and (2) the model of the Federal-State River Forecast Center (FRC). The RSRP effort is being currently conducted in close coordination with that of other NASA Grant participants, particularly the efforts of the Algazi group on the Davis campus as described in Chapter 2 of this progress report. This cooperative effort involves an analysis of the sensitivity of the RFC runoff forecast model to its input components, particularly the model response that results from using a remote sensing-aided evapotranspiration estimate as one of the major input parameters.

A primary objective of this work is the preparation of procedural manuals, describing the step-wise process which might best be followed by managers of water resources in using remote sensing as an aid to water resources inventory, development and management.

The work that is about to be presented consists of research activities during the present reporting period and a discussion of the remaining future research. Several phases of our work are being completed through the preparation of procedural manuals. These procedural manuals include a complete version of Snow Areal Extent Estimation, a version of Snow Water Content Estimation, Outlines of Solar Radiation Estimation and Estimation of Water Loss to th Atmosphere, and the project outline for multiple resources complex inventory and management. Our research activities for the multiple resource complex project are building on the above mentioned water resource research, but will not be completed until May 1979.

3.100 WORK PERFORMED SINCE MAY 1977

3.110 Completion of Work Related to Watershed Analysis

3.111 Watershed Boundary Determination

Determination of the watershed boundary on the Landsat digital data is necessary to:

1. Accurately determine the water input and output for the watershed;
2. Minimize computer expenses by keeping the area that is to be analyzed to the smallest possible dimensions;
3. Provide an accurate and meaningful summation of computer generated data for the watershed;
4. Provide useful visual presentation and hard copy reproduction of results.

The location of the watershed boundary is done in conjunction with the geometric transformation of the Landsat digital data. The watershed boundary is carefully determined and annotated on the same USGS 1:120,000 topographic series maps as are used in locating the control points. The watershed boundary is digitized at the same time as the control points. This gives a geometric description of the watershed boundary relative to the control points.

The watershed boundary and locations of control points within and around the Middle Fork of the Feather River Watershed are shown in Figure 1. The digitized boundary can be incorporated with the Landsat digital data using the transformation equations previously generated. The required transformation equations are part of a series of algorithms, known as MAPIT, developed by RSRP personnel and used in this study.

3.112 Geometric Correction of Landsat Data

As received from the EROS Data Center, the Landsat digital data contained a certain amount of spatial distortion as compared with map projections commonly in use. In order to rectify this data, it was necessary to lay out a network of geometric controls over the specific Landsat scenes. A transformation equation was then generated to convert the Landsat data to its planimetric position. This geometric rectification of Landsat digital data is a necessary step to facilitate further analysis and to enhance the appearance of visual results.

Much of the topographic data used in this watershed analysis research is derived from USGS topographic series maps based on the transverse mercator projection system. This data includes elevation, slope, aspect, and watershed boundaries. Other necessary data, such as location of the ground meteorological stations within and around the watershed, should be determined separately. Watershed-wide distribution of data collected at these stations must be comparable (location-wise) to the Landsat digital data and its manipulations. The final products of the research effort must all be of common register, as far as the boundary of the research area is concerned. This makes it necessary to correct the Landsat data to the map projections used by the other data sources, in this case the transverse mercator projection system.

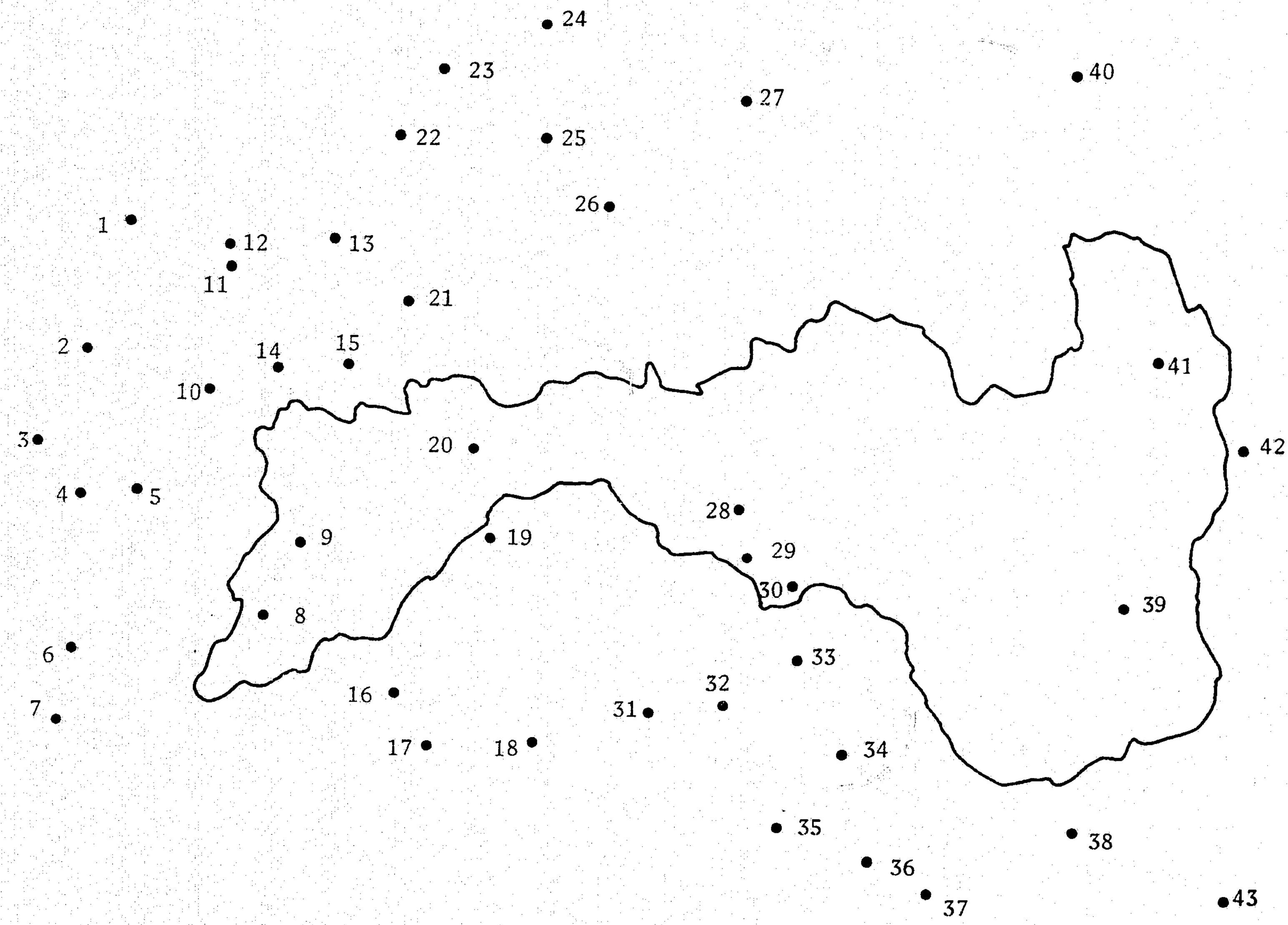

Figure 1 . Boundary limits and location of control points within the watershed covering the Middle Fork of the Feather River.

A total of 43 control points were located in and around the Middle Fork of the Feather River Watershed. These points were related directly to river courses or water bodies. Control points located along river courses were located at major river/stream intersections and on bends in the rivers. Dams on lakes and reservoirs provided for the most accurate control point location available due to the almost vertical displacement of apparent lake (or reservoir) shorelines. Control points were located both on the Landsat digital data and on USGS 1:250,000 topographic series maps. These control points were first located on the topographic maps. Then they were identified on the Landsat digital data, and displayed in a simulated infrared color enhancement form on a color television monitor. A variable x, y cursor on the color television monitor allowed each control point to be identified in terms of its nearest Landsat picture element (pixel). Locations of the control points based on USGS topographic maps were digitized to provide their coordinate information. This coordinate system was then statistically related to the x, y coordinate values for the control points as located on the Landsat digital data. A linear regression model was then generated to give the transformation equation necessary to geometrically relocate the Landsat digital data to the transverse mercator map projection data.

3.113 Vegetation/Terrain Analysis

Knowledge of the spatial distribution of vegetation/terrain features in the Middle Fork of the Feather River Watershed is necessary for generation of albedo indices. Albedo is used directly as an input to the shortwave radiation model, which ultimately is used in the watershed-wide calculation of evapotranspiration.

By definition the albedo or reflection is the ratio of the reflected to the incident radiation, usually expressed as a percentage. The values of albedo for the total range of solar radiation and in some cases for the visible electromagnetic range only are shown in Table 1. The figures given in this table illustrate what can be observed directly from an airplane. The sea appears darkest, relative to white strips of surf and sand dunes. Woods show up darker than fields, and snow covered areas are light. One can see here how the absorption capacity for incident solar radiation varies and how this affects the whole heat economy and therefore evaporation and evapotranspiration. Albedo is influenced not only by the nature of a surface, but also by its moisture content at any time, i.e., wet surfaces appear darker than dry surfaces.

The procedure used to develop the vegetation/terrain distribution for the Middle Fork of the Feather River is based upon the computer-aided classification of Landsat-1 digital data. Basically this classification involves the selection ot training statistics based on the unsupervised initial classification test sites located throughout the watershed and surrounding areas. Those training statistics, relating to specific vegetation/terrain classes, are then used to derive the final, watershed-wide classification.

Sixteen classes of vegetation/terrain features were selected for consideration in the classification. The initial, unsupervised classifications of the test sites were then organized into the appropriate vegetation/terrain classes. The vegetation/terrain classes used for this are as follows:

TABLE 1

Stand	Albedo Percent	Source
Fresh snow cover	75-95	Geiger
Dense cloud cover	60-95	"
Old snow cover	40-70	"
Clean firn snow	50-65	"
Ice, sparse snow cover	69	Smithsonian table
Clean glacier ice	20-50	"
Light sand dunes, surf	30-46	Geiger
Sandy soil	15-40	"
Meadow and fields	12-30	"
Meadow, low grass	15-25[a]	Smithsonian table
Field, plowed, dry	20-25[a]	"
Densely built-up area	15-25	Geiger
Woods	5-20	"
Dark cultivated soil	7-10	"
Douglas-fir	13-14	Avery
Pine	14	Brooks
Conifers	10-15	Budyko
Deciduous forest, fall	15[a]	Krinov
Deciduous forest, summer	10[a]	"
Coniferous forest, summer	8[a]	"
Coniferous forest, winter	3[a]	"
Meadow dry grass	10[a]	"
Field Crops, ripe	15[a]	"
Spruce	8-9	Baumgartner
Earth roads	3[a]	Krinov
Black top roads	8[a]	Sewing Handbook
" " "	9[a]	Krinov

ORIGINAL PAGE IS
OF POOR QUALITY

Stand	Albedo Percent	Source
Concrete road	35[a]	Krinov
Buildings	9[a]	"
Mountain tops, bare	24[a]	"
Clay soil dry	15[a]	Sewing Handbook
Clay soil wet	7.5[a]	"
Clouds, stratus overcast, 0-500 feet thick	5-63	"
Clouds, stratus overcast, 500-1,000 feet thick	31-75	"
Clouds, stratus overcast, 1,000-2,000 feet thick	59-84	"
Clouds, dense, opaque	55-78	"
Clouds, dense, nearly opaque	44	"
Clouds, thin	36-40	"
Clouds, stratus, 600-1,600 feet thick	78	"
Clouds, stratocumulus overcast	56-81	"
Clouds, altostratus, occasional breaks	17-36	"
Clouds, altostratus, overcast	39-59	"
Clouds, cirrostratus and altostratus overcast	49-64	"
Clouds, cirrostratus overcast	44-50	"

Whole earth: From measurements on the bright and dark portions of the moon, Danjon[b] has calculated the albedo of the earth in the visible portion of the spectrum at 39 percent. Fritz[c] has extended the calculation to include infrared and ultraviolet radiation, obtaining a total albedo of the earth of 35 percent. Baur and Philipps[d] have calculated the total albedo to be 41.5 percent

[a]visual albedo

[b]Danjon, A., Ann. l'Obs. Strasbourg 3, No. 3, 1936, P. 139

[c]Fritz, S., Bull. Amer. Meteorol. Soc., Vol. 29, 1948, p. 303; Vol. 31, 1950, p. 251; Journ. Meteorol., Vol. 5, 1949, p.277

[d]Baur, F., and Philipps, H., Gerl. Beitr. Geophys., Vol. 42, p.160

Red fir forest	Grassland-meadow
Mixed conifer forest	Marshland
Eastside timberland-chaparral complex	Agriculture/rangeland
Mixed hardwood forest	Water
Riparian hardwoods	Urban
Foothill pine-oak woodland	Exposed soil
Brush-chaparral complex	Exposed bedrock
Sagebrush	Serpentine-vegetation complex

Ten test sites were selected in and around the Middle Fork of the Feather River Watershed for use in determining how closly these vegetation/terrain types could be identified on the Landsat digital data. These sites were selected from 1:120,000 scale high-altitude aerial photography of the watershed area, as acquired by the NASA Earth Resources Program. Each of the sites is approximately 10,000 acres in size (100 x 100 Landsat picture elements). The sites are distributed throughout the watershed as shown in Figure 2. All the test sites were identified on the Landsat digital data, and on 1:30,000 to 1:120,000 scale infrared Ektachrome aerial photography. A computer compatible tape of the ten sites was made from the Landsat digital data. The ten 100 x 100 pixel sites on the computer compatible test were clustered using unsupervised classification techniques according to an algorithm in a computer program known as ISOCLAS.

ISOCLAS applies a modified version of the clustering algorithm known as ISODATA to multispectral scanner data. The acronym ISODATA stands for Iterative Self-Organizing Data Analysis Technique (A). As its name implies, the algorithm is arrived at through an iterative procedure which groups similar "objects" into sets called clusters. The algorithm was originally developed by Hall and Ball, 1965 and 1967. A clustering technique based on ISODATA and suitable for use in processing multispectral scanner data was developed by Kan and Holley, 1972. To distinguish between the original and revised programs, the multispectral scanner version became known as ISOCLAS.

This procedure will, ideally, separate all of the data into distinct groups or clusters, the center of each cluster being represented by its mean. The process is initiated by assigning each data point to the nearest estimated cluster center (absolute distance is calculated to each cluster mean). After all of the data has been assigned, new means are calculated and tests are made to see if clusters should be split or combined. A cluster is split if the standard deviation of the cluster exceeds a specific threshold value. Two clusters are combined if the distance between cluster centers is smaller than the specified threshold. A cluster is deleted if it has fewer than some specified number of points. The data is reassigned, after each split or combining iteration, to the new clusters and the process continues until the desired number of iterations has been obtained.

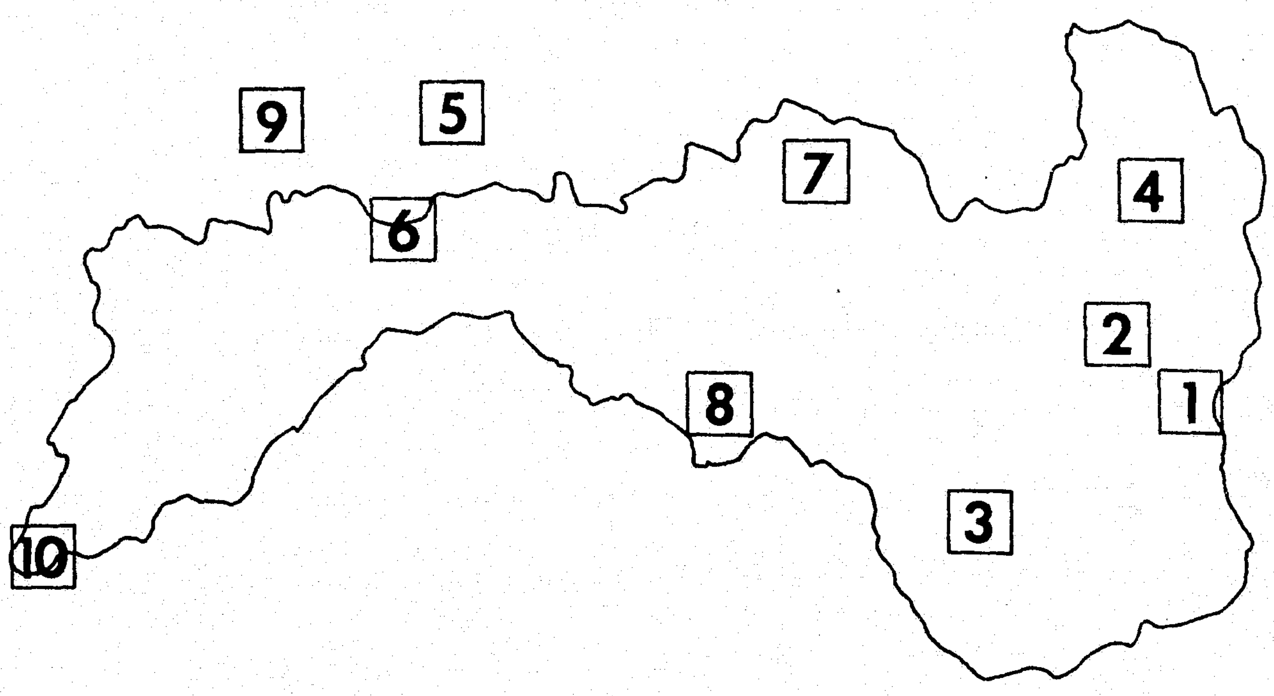

Figure 2. Distribution of Landsat test sites throughout the Middle Fork of the Feather River Watershed and surrounding area.

Area 1	Sierra Valley Mountains
Area 2	Sierra Valley Area 1
Area 3	Sierra Valley Area 2
Area 4	Franchman Reservoir Area
Area 5	Quincy/American Valley
Area 6	Serpentine Area
Area 7	Davis Lake Area
Area 8	Gold Lake Area
Area 9	Silver Lake Area
Area 10	Middle Fork /Lake Oroville

Since ISOCLAS is used in this case as a training device for the watershed-wide image classification of vegetation and terrain features, two approaches were evaluated on the initial ISOCLAS runs. In the first approach, all ten test sites were considered to be a portion of the same population of picture element reflectance values. The program was instructed to go through twelve iterations to reach no more than forty separate clusters. In this algorithm, the same minimum distance was sought between the cluster means. Also the same maximum (threshold) standard deviation was sought among the picture element reflectance values that make up each cluster. Consequently, clusters found in one test could be absolutely related to clusters found in other test sites without any intermediate statistical manipulation. The advantage of using this technique relies on the established statistical relationship between clusters in each test site. Instructions to the image classification program, which will ultimately analyze the watershed for vegetation/terrain classes, are relatively simple and straightforward. Similar (but not exactly the same) vegetation/terrain groups, easily identified on the aerial photography, were grouped into single clusters, due to the limitations of the number of classes available in the program. Although only fifty clusters are possible using this technique, it was was estimated that approximately one hundred clusters would be needed to adequately characterize the entire range of vegetation/terrain classes found in the watershed when all test sites were analyzed in this fashion. A still more detailed classification might have been desirable, but was considered to be out of the scope of this project.

In order to minimize the restrictions whichthe ISOCLAS routine placed on the absolute number of clusters available, each test site was analyzed independently. The ISOCLAS program was again instructed to consider twelve iterations of no more than forty classes. However, using this approach it was possible to have up to forty clusters for each test site. It was found that, while not perfect, this technique represented the desired vegetation/terrain classes much more accurately than in the previous technique. Confusion in vegetation/terrain classes still existed, however, but generally in features with similar reflectance values. The fact that some vegetation/terrain classes were confused in the ISOCLAS clusters even though they were distinct on the aerial photography, probably can be attributed to the differences in texture of different features. This texture consideration is a function to which the ISOCLAS analysis is not sensitive.

In order to display the ISOCLAS clusters in a more meaningful manner, ratios of the band 7 to band 5 reflection mean values of each cluster were determined. These values were then ranked and a color was assigned to each value (Clark, 1946). The ratioing method is based on the fact that vegetation in various forms and in different conditions (especially in the healthy condition) reflects relatively large amounts of near-infrared (band 7) energy compared to visible red wavelength (band 5) energy. Thus, the higher the band 7:band 5 ratios are likely to indicate vegetation. Of course, different plant species have different band 7:band 5 ratios; therefore, it was found possible to assign spectrally ordered colors to the numerically ranked band7:band 5 ratios. Other terrain features, such as bare soil, bare ground, and water tend to have their own unique ratios, thus making it relatively easy to identify them. The band 7:band 5 ratio-ranked display presents a more meaningful representation of the ISOCLAS clusters than the display utilizing the random assignment of colors to the clusters (Khorram and Katibah, 1977).

The final assignment of spcific ISOCLAS clusters to vegetation/terrain classes is the result of associating the band 7:band 5 ratio visual display results with the high-altitude aerial photography and the computer printout of the ISOCLAS clusters. Specifically, areas represented on the 7:5 ratio display which can be accurately identified on the aerial photography as a specific vegetation/terrain class are located on the computer printout. The computer printout is organized on an x-y coordinate format with a given symbol representing each cluster. All clusters found within the area identified from the coordinates are then placed within the vegetation/terrain class previously identified. This procedure is done until all clusters have been assigned to a specific vegetation/terrain class. Based on this method the identification key for each vegetation/terrain class is then prepared.

Statistical summaries for each cluster of ISOCLAS form the basis for the training of a classification routine which will ultimately place every picture element into its predetermined vegetation/terrain class. While the 7:5 ratio method provides useful information for cluster distribution, it cannot be expected to decide, statistically, to group clusters into vegetation/terrain classes. The development of a method for measuring class (or cluster) separability is extremely important due to the individual clustering performed by ISOCLAS on each of the ten test sites. A methodology for the determination of class separability based on the Scheffe method of multiple comparison has been applied to this analysis (Thomas and Vasick, 1975). Statistical analysis using the Scheffe method allows significance probabilities to be calculated for all cluster pairs. These probabilities are displayed in matrix form. Class pairs with their significance probabilities below specific threshold values are considered to be separable for classification purposes. Thus individual clusters can be statistically compared to other clusters within a vegetation/terrain group and all other clusters in the vegetation/terrain classes.

The statistical description of each cluster selected in terms of mean, standard deviation, and covariance are then used to drive a discriminant analysis routine called CALSCAN. CALSCAN is a maximum likelihood classifier based on the Purdue University image classification program, LARSYSAA. The CALSCAN program utilizes the ISOCLAS cluster training statistics to classify each picture element within the available population into a specific vegetation/terrain class.

The vegetation/terrain classification based on the above-mentioned technique is completed and shown in Figure 3. Based on this vegetation/terrain classification, an albedo index was assigned to each class and consequently the albedo map of the study area has been prepared and is shown in Figure 4.

3.114 Topographic Analysis

The amount of solar radiation and consequent vegetation density and composition, evaporation, and evapotranspiration are all affected by topographic characteristics of the watershed.

The values of the solar radiation which is actually received on the earth's surface depend upon the transparency of the atmosphere. Some of

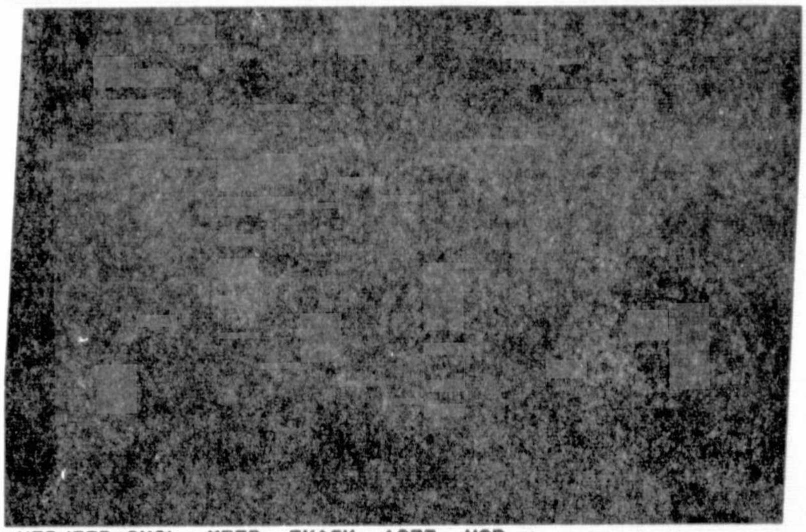

Figure 3. Vegetation/terrain map for the Middle Fork of the Feather River Watershed. Identification key:

Color	Vegetation/Terrain Type
Lavender	Sagebrush
Purple	Sagebrush/Bare Soil
Off White	Bare Soil
White	Rock
Orange	Agricultural
Yellow	Marsh/Mesic Grassland
Red	Mixed Conifer
Orange/Red	Red Fir
Light Blue	Riparian Hardwoods
Blue/Green	Mesic Brush
Dark Green	Brush
Light Green	Oakwood/Xeric Brush
Dark Blue	Water

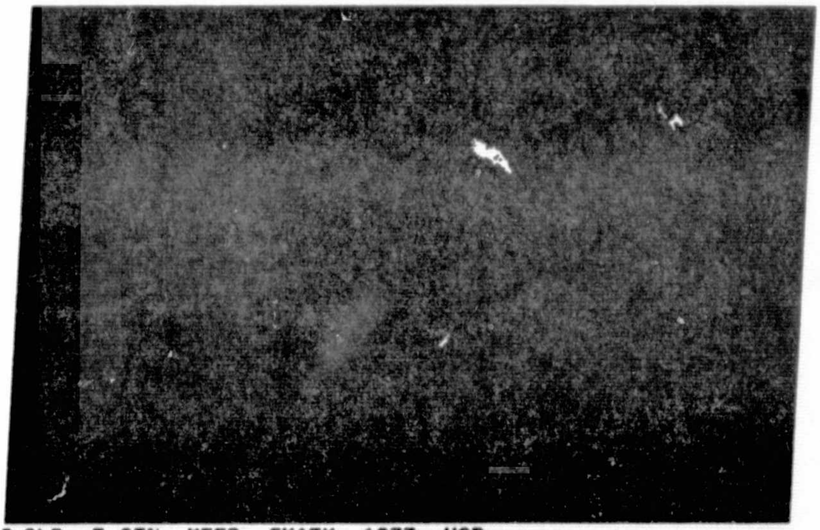

Figure 4. Areal Distribution of albedo for the Middle Fork of the Feather River Watershed, in percent, based on vegetation/terrain analysis.

White	= 5	Dark Green	= 14
Dark Blue	= 9	Light Blue	= 15
Purple Blue	= 10	Orange	= 18
Yellow	= 11	Red	= 22
Light Green	= 12	Brown	= 25
Green	= 13		

the incident solar radiation is reflected, some scattered, and some absorbed by the atmosphere. In the absence of clouds these amounts are relatively small and quite constant. The atmospheric transmission coefficient varies from about 80 percent at the time of the winter solstice to about 85 percent at the time of the summer solstice.

Cloud cover and density cause the largest variations in the portion of solar radiation transmitted by the atmosphere. Similar to the cloud effects, the environmental conditions such as a forest canopy exert a powerful controlling influence on net allwave radiation exchange in hydrologic processes. However, the forest canopy has a different effect than that of clouds, particularly with respect to shortwave radiation. While both the clouds and trees restrict the transmission of insulation, clouds are highly reflective, while the forest canopy absorbs much of the insulation. Consequently, the forest canopy tends to be warmed up and in turn gives up a portion of the energy for evapotranspiration. It is this portion of the solar radaation which is used for evapotranspiration that is of interest for the water yield prediction models. The values for solar radiation in turn are site-specific and consider the effects of elevation, slope, aspect, albedo, latitude, and cloud cover (Khorram, et al., 1976). Elevation contour data of USGS topographic maps, 15' series, were used to construct the elevation, slope, and aspect maps. The procedure involves the orientation of each Landsat picture element in the watershed. Each picture element (pixel) is defined in terms of x,y and z coordinate dimensions. The x and y coordinates locate the center of the pixel while the z coordinate defines the elevation (average). Each pixel can be "tilted" and/or rotated. The tilt and rotation functions are considered to be the slope and aspect of the pixel, respectively.

Selection of control points is the first step in watershed terrain analysis. Control points were selected on USGS topographic maps along the contour lines for elevation. Elevation contour maps were digitized in x, y, z coordinates and then control points were selected to represent these contour lines. These control points were described in terms of Universal Transverse Mercator grid units (x and y coordinates) and elevation (z coordinate). The control points are then used as an input for elevation interpolation. A computer-assisted interpolation technique, the same as the one used for interpolating climatic parameters described in Section 3.122 of this report, was used for elevation interpolation and construction of elevation maps. The interpolated elevation data constructed by this method is based on the actual z coordinate representing a zone of elevation per pixel rather than an absolute value.

A "normal" vector was then determined for slope and aspect calculation. This "normal" vector is a directional variable that originates in the center of each pixel and locates a direction that is 90 degrees to the surface of the pixel. This vector is expressed in triple coordinates (n_x, n_y, n_z), where the center of the pixel is considered to be the origin (o, o, o), and the triple coordinates are the coordinates in three dimensions (x, y, z). (See May 1976 Grant report for further detail.

The watershed-wide maps of elevation, slope, and aspect for the Middle Fork of the Feather River Watershed are shown in section 3.150 of this report.

3.120 Completion of Ground Climatic Data Collection

Climatic data required for use in the remote sensing-aided system for estimating evapotranpiration is not fully available within the watershed covering the Middle Fork of the Feather River. The number of meteorological stations in this catchment is limited. Also, data pertaining to only a few types of climatic parameters has been taken at each station. In our previous studies, a similar problem existed within the Spanish Creek Watershed, and the personnel of the Remote Sensing Research Program, with the cooperation of several U.S. Forest Service employees working in the Plumas National Forest, collected additional climatic data for that area. This data was composed of "Weather Bureau Class A" evaporation pan data and evaporimeter data. Evaporimeters were designed by RSRP personnel with the cooperation of the California Department of Water Resources at Red Bluff. Both the evaporation pan and the evaporimeter data were collected simultaneously. This additional data was collected at each of four localities on the Plumas National Forest, viz., Mohawk, Mount Hough, Quincy, and the U.C. Forest summer camp at Meadow Valley.

Since the date for application of ET models for the new watershed (MFFR) was to occur in 1975 (to correspond to the analysis date of the RFC hydrologic model by the Algazi group at U.C. Davis), there cannot be any meaningful pan evaporation and evaporimeter data collected for this new watershed for this date.

According to the sensitivity analysis of the RFC model by the U.C. Davis group, the runoff variation is most sensitive to evapotranspiration in the springtime. The RFC water yield models showed 66% sensitivity to evapotranspiration during the springtime versus 22% for all other seasons. Therefore, the spring of 1975 was the first time during which to incorporate ET information into our water yield forecast model. This eliminates the use of some of the climatic data collected by the Forest Service ranger stations during the fire season (middle of May to middle of October).

There are only fifteen ground meteorological stations within our watershed which collect climatic data. These stations are shown in Table 2. The data types collected in these stations consist mostly of precipitation and temperature (dry bulb, wet bulb, maximum and minimum). Very few of these stations collect wind data and report the atmospheric condition with regard to cloudiness.

3.121 Interpolation of Climatic Data

The algorithm used for interpolation of climatic data (based mainly on temperature and humidity), elevation, slope, and aspect is described by the

Table 2. Existing ground meteorological stations within the Middle Fork of the Feather River Watershed

Station Name	Latitude(N)	Longitude(W)	Elevation(Feet)
Brush Creek	39 41'	121 21'	3560
Bucks Creek Pump House Challenge	39 55'	121 20'	1760
Forbestown			2900
Greenville Ranger Station	40 08'	120 56'	3560
Mohawk Ranger Station	39 47'	120 38'	4370
Oroville Ranger Station	39 32'	121 34'	300
Plumas Creek State Park	39 45'	120 42'	5165
Portola	39 48'	120 28'	4850
Quincy	39 55'	120 57'	3408
Sagehen	39 26'	120 14'	6337
Sierra City	39 34'	120 38'	4150
Sierraville Ranger Station	39 45'	120 22'	4975
Vinton	39 49'	120 11'	4950
Woodleaf Oroleve	39 31'	121 11'	3340

following equation:

$$T(x,y) = \frac{\sum_{i=1}^{n} \frac{T_i}{(\Delta_i)^2}}{\sum_{i=1}^{n} \frac{1}{(\Delta_i)^2}}$$

where: Δ_i = the distance from (x,y) to control point i,

T_i = the temperature of control point i,

n = the number of control points within range of (x,)

T(x,y) = the temperature of point (x,y).

This equation uses the x,y,z coordinates of the control points to assign a z coordinate (temperature) to each Landsat pixel.

The input source for interpolation of climatic data was the data collected from fifteen existing ground meteorological stations, and for terrain analysis consisted of digitized contour lines based on USGS topographic maps.

3.130 Analysis of NOAA-4 Satellite Data

To obtain temperature profiles of the Middle Fork of the Feather River Watershed area, we used Very High Resolution Radiometer (VHRR) data from the NOAA-4 satellite. The VHRR is a two-channel scanner which detects energy in both the visible spectrum (0.6 to 0.7 micrometers) and the thermal infrared (10.5 to 12.5 micrometers). The IR data can be converted to equivalent black-body temperature by means of calibration information recorded along with the data.

The raw data used for this study consisted of digital magnetic tapes obtained from U.C. Davis grant participants. These tapes had been copied from NOAA tapes at 1600 bits per inch (BPI) and written at 800 BPI.

The procedure used to obtain the temperature profile will be described in more detail. It consisted of the following steps.

- Generation of a geometrically corrected IR image
- Smoothing images line-by-line to reduce both noise and the effect of variation in the IR sensor (visible as "banding" in the image)
- Transformation of raw IR values to temperatures by a two-step process:
  a. Transformation of raw IR values to voltages
  b. Transformation of voltages to temperatures
- Rotation of the image through the assigning of coordinates consistent with other data used in the models.

The NOAA scene used for data analysis covered an area of 200 x 200 pixels. It included the Feather River Watershed. It also included lakes Tahoe, Pyramid, and Almanor for control point and temperature calibration verification purposes. As a preliminary step, we obtained a histogram of raw IR values for the area, and determined the apparent range of valid data. (This range was 125-129, or about 1-43^{o}C, for May 16, 1975.)

3.131 Geometric Correction and Smoothing of the Imagery

For geometric correction, we adapted the NOAA-NESS's* original program, modified by UC Davis grant participants, to our data processing system. This program corrects panoramic distortion, taking into account the earth's curvature and skew distortion due to the earth's rotation, on the basis of an algorithm developed by Legeckis and Pritchard (1976). When the geometrically corrected IR image was displayed, "banding" was observed, i.e. many lines in the image appeared lighter or darker than the surrounding lines. This was assumed to be the result of variation in the IR sensor. Since we did not have line-by-line calibration data for two of the three dates of interest, we decided to develop a program to smooth the image. The basic assumption here was that the values within one line in the image were consistent, but that those within adjacent lines might not be consistent. The program to eliminate banding first computes the mean M_n for the 200 pixels in each line n, not including pixels which have values outside the range of normal data. Secondly, it computes an adjusted mean, which was taken to be a weighted average A_n.

$$A_n = \sum_{k=-2}^{2} W_k M_{n+k}, \quad \text{where } W_k = C_{5,k+3}$$

Then the value of every point in line n was incremented by the integer closest to $(A_n - M_n)$. The sum of all the increments for the May 16, 1975 date was -1. One line was incremented by +3, thirteen lines by ± 2, and 92 by $\pm$ 1. A change of 2 is approximately equivalent to 1 centigrade degree.

3.132 Elimination of Noise

In the IR image with which we worked, about 0.7 - 0.8% of the pixel values were noise. Most of the noise consisted of zeroes or abnormally low values for 2-4 consecutive pixels. Noise elimination was accomplished by a two-step process. In step one, the limits of valid data were entered into a program, and pixel values outside this range were changed to the average of values of the pixels above and below. (In some cases in which one of these was also noise, it was not used in the calculation.) After this step had been accomplished there remained a small number of pixels whose values were clearly consistent with all others in their area. This was corrected in step two, in which any pixels with values more than R units outside the range of values (as defined by the pixels before and after them along the line) were replaced by the average of all the values. We used R=10.

At this stage of processing, all apparent noise had been eliminated and there remained only slight banding of the visible data.

3.133 Temperature Calibration

The transformation of raw IR values to temperature data was done according to a procedure provided by UC Davis grant participants. This technique is a

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*NESS - National Environmental Satellite Service

modified version of the standard NOAA procedure, which does not work for data acquired prior to September 1975. The input used consisted of the following data from the line headers:

1) Voltage wedge values W_o, ..., W_5

2) Space view average S

3) IR calibration target value IRC

4) Thermistor readings T1, T2

For the May 16 data, we used means of the values from line headers for the watershed area. For the May 24 and 29 data, we had available only a single line of header information.

a) Transformation to voltages

The W_i and S were input into a program which used the formula $V_i=(W_5-S)/(W_5-W_4)+5.8+(i-5)$ to compute voltages V_o, V_1, ..., V_5. Then for each raw value, it interpolated between wedge values to find the corresponding voltage.

b) Voltage-to-temperature conversion was done as follows:

1) Obtain V_{T1} and V_{T2} from T1 and T2 by interpolating between wedge values.

2) Compute T_c as the mean of $T_{T1}=3.60V_{T1}+11.40$ and $T_{T2}=3.57V_{T2}+11.68$.

3) Compute V_c from IRC by interpolation.

4) On special non-linear graph paper provided by NOAA, titled "Radiometer Radiance Calibration Curves," we drew a straight line through (0^oK, 5.8V) and (T_c,V_c). We used this line to convert a voltage to temperature.

For the final conversion, we ran a linear regression on 14 points that we read off the graph. This was done to obtain an equation in which temperature would be a dependent variable and V, V^2, $1/(5.8-V)$ and $(\ln(5.8-V))^{1.5}$ would be independent variables. This regression gave an R^2 value of .9999+. The residuals were 0.1 or less with the exception of 0.27 for 12°C and -0.24 for 15.8°C, where the graph appeared to have an irregular scale.

3.140 Snow Quantification

The detailed description of techniques for using remote sensing as an aid in estimating (1) areal extent of snow and (2) water content of snow is documented as Appendices I and II of this report, respectively. These two techniques together comprise the snow quantification research that our group currently is completing. Because both of these techniques have demonstrated their ability to characterize efficiently the resource parameters which they were designed to estimate, procedural manuals have been prepared for each technique.

Because the acquisition of data on snowcover is the first step in the snow water content estimation procedure, the two systems are linked through

information and data gathering requirements. To help the potential user of such snow quantification systems, refinement of both techniques and the preparation of procedural manuals constituted the primary research objectives of our group for the May 1976 to May 1977 reporting period. It was determined that the most significant single improvement in areal extent of snow estimation (and hence in snow water content estimation) could be achieved by optimizing the basic estimation elements, i.e., the image sample units (ISU's).

Since the May 1977 annual report, we have completed our research effort on the image sample unit optimization phase of the procedure for estimating the areal extent of snow. The interpretation results and statistical summaries are shown in Table 3. The application of this data in image sample unit size optimization is described in the Procedural Manual, "Remote Sensing As An Aid in Determining the Areal Extent of Snow," found as Appendix I of this report.

3.150 Solar Radiation Estimation

Solar energy values in general, and net solar radiation values in particular, are the key parameters in the earth surface energy-balance models that are utilized in hydrologic modeling. Net solar radiation is one of the most important inputs to the evapotranspiration estimation models that have been developed under this grant.

Total incoming solar radiation, Q_s, is defined as the sum of the direct and diffused (or indirect) shortwave radiation reaching the ground through the atmosphere. Some of this incident radiation is reflected back to the atmosphere, $\alpha(Q_s)$. It is called reflected radiation; and the rest is absorbed by objects on the earth's surface. Part of the absorbed radiation is dissipated to the atmosphere from the ground as longwave radiation. In turn, a portion of this dissipated longwave radiation is absorbed by the clouds and atmosphere particles and part of it is returned to the ground. This returned longwave radiation from the atmosphere to the ground is called atmospheric radiation. The difference between upgoing and atmospheric longwave radiation may be defined as the net longwave radiation, Q_nL. Net radiation (Q_n), as it it shown in the following equation, is the algebraic sum of the net shortwave radiation, $(1-\alpha)Q_s$, and net longwave radiation, Q_nL.

$$Q_n=(1-\alpha)Q_s \pm Q_nL$$

The reflection of albedo, α, is the ratio of the reflected to the incident radiation, usually expressed as a percentage. The albedo values in this study were calculated from vegetation/terrain data. The vegetation/terrain analysis was based on Landsat-1 digital tapes employing a maximum likelihood classification scheme. This classified data was then converted to albedo indices. These albedo indices for various types of vegetation and ground cover are reported later in this section.

A series of mathematical equations has been used to estimate the total incoming solar radiation, Q_s. The inputs to these equations include a solar constant, time of the year, solar declination, terrestrial latitude, slope inclination, and slope azimuth (aspect). Slope and aspect maps were made from

Table 3. The summary of statistical results of the areal extent of snow estimation for 4 April 1973.

DESCRIPTIONS	GRID NO. 1 (204 Ha)	GRID NO. 2 (459 Ha)	GRID NO. 3 (815 Ha)
Corrected estimate of the actual areal extent of snow (in hectares)	408062.70	395365.17	452102.26
Uncorrected estimate of the areal extent of snow (in hectares)	426688.44	424492.38	467948.55
Population ratio estimator	.9563	.9314	.9661
Standard deviation of the corrected areal extent estimation (in hectares)	9981.36	16864.54	24439.40
Ninety-five percent confidence interval around the actual areal extent of snow values (in hectares)	401043. $\leq$ SAE $\leq$ 415082.	361928. $\leq$ SAE $\leq$ 428802.	403386. $\leq$ SAE $\leq$ 500818.
Total number of image sample units inventoried	4229	1870	1064
Total surface area inventoried (in hectares)	862716.00	858330.00	867160.00
Total number of image sample units used in the testing phase	339	113	81

elevation data based on USGS topographic maps. First each picture element (commonly called a pixel) was digitized in x, y and z coordinate dimensions. X and y coordinates locate the center of the pixel and each pixel can be "tilted" and/or "rotated" in any direction. The tilt and rotation functions are considered to be the slope and aspect of the pixel, respectively (see section 3.114 of this report).

The net longwave radiation values are based on temperature and cloud cover data.

A detailed description of the procedures used for total incoming solar radiation, net longwave radiation, elevation slope, and aspect quantifications is documented in our May 1976 annual progress report under the present grant.

Temperature is one of the main inputs to these solar radiation models. The areal distribution of temperature data was calculated by an interpolation algorithm developed by our RSRP personnel using data from all fifteen ground stations. Percentage distribution of temperature data is shown in Table 4.

Currently, we are developing a technique for use in these solar radiation models of infrared data acquired by NOAA-4 satellites. This technique is nearly completed and we are expecting to get more accurate temperature data from meteorological satellites for our modeling purposes. The methodology for solar radiation estimation is designed to readily accept NOAA satellite data. The watershed-wide elevation zones (based on the digitization of contour lines and computer interpolation between these contour lines) are shown in Figure 5. Percentage distribution of elevation data is shown in Table 5. These zones are based on the topographic maps (15 min. quads) of the USGS which were digitized and then clustered into elevation zones with 400 foot intervals. Slope and aspect maps of the Middle Fork of the Feather River Watershed are shown in Figures 6 and 7, respectively.

The outputs of these models are areal distributions as well as statistical summaries of daily net shortwave radiation (the difference between total incoming and reflected), net longwave radiation (the difference between longwave radiation emitted from the ground and returned longwave radiation from the atmosphere), and net solar radiation. The net solar radiation map of the Middle Fork of the Feather River Watershed for 16 May 1975 is shown in Figure 8. Percentage distribution of net solar radiation data is shown in Table 6.

The determinations of net solar radiation are used directly as inputs to evapotranspiration models.

Table 4. Percentage distribution of temperature in $^{\circ}F$ over the Middle Fork of the Feather River Watershed.

Temp.	Percent	Temp.	Percent
30-35	2.1	49	37.2
35-40	6.2	50-52	2.1
40-45	12.0	52-55	7.3
45-48	7.8	55-58	8.1
48	9.0	58-61	8.0

Table 5. Percentage distribution of elevation zones in feet, above mean sea level, within the Middle Fork of the Feather River Watershed.

Zone Midpoint	Percent	Zone Midpoint	Percent
1200	.2	4800	16.6
1600	.8	5200	18.0
2000	.8	5600	12.8
2400	1.3	6000	14.7
2800	1.6	6400	11.3
3200	1.4	6800	8.8
3600	1.5	7200	2.6
4000	3.6	7600	.6
4400	3.1	8000	.3

Table 6. Percentage distribution of net solar radiation values in ly/day for May 16, 1975, for the Middle Fork of the Feather River Watershed.

Net Radiation	Percent
10-200	2.6
210-350	6.2
360-400	12.9
410-430	19.5
440-450	35.6
460	12.2
470-500	10.8
510-560	0.2

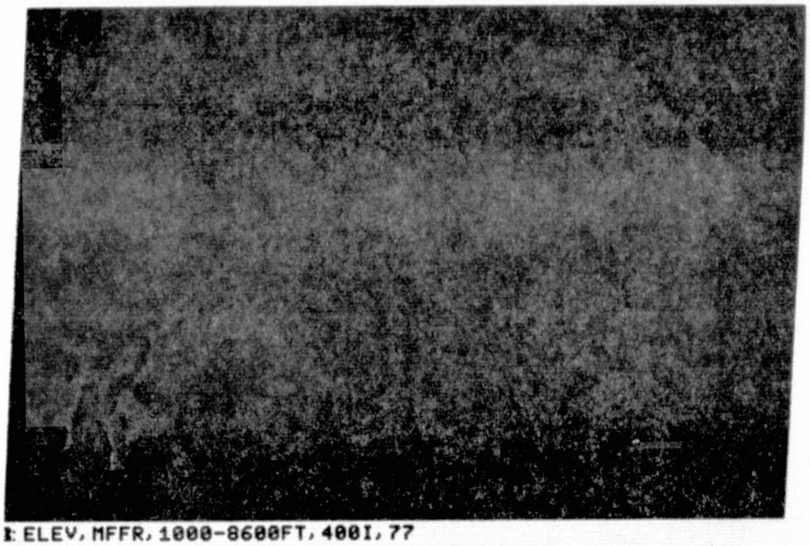

Figure 5. Areal distribution of the elevation zones for the Middle Fork of the Feather River Watershed, in feet (MSL).

Red	= 1200	Light Green	= 5200
Orange	= 1600	Blue Green	= 5600
Purple	= 2000	Dark Yellow	= 6000
Brown	= 2400	Dark Blue	= 6400
Yellow	= 2800	Dark Purple	= 6800
Green	= 3200	Blue	= 7200
Light Brown	= 3600	Purple	= 7600
Light Yellow	= 4000	Darker Purple	=8000
Yellow Green	= 4400	Gray	= 8200
Dark Green	= 4800		

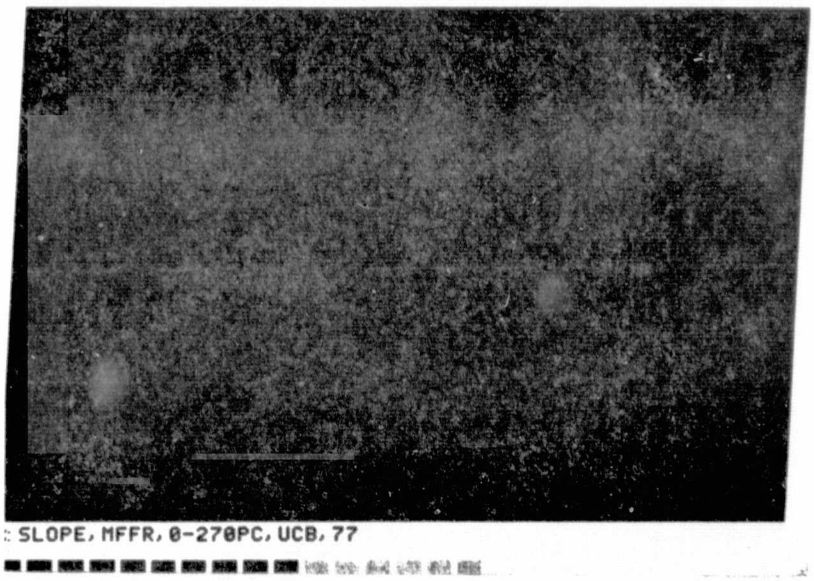

Figure 6. Slope map of the Middle Fork of the Feather River Watershed, in percent.

Black	= Flat	Dark Green	= 42-60
Red	= 2-4	Purple	= 62-80
Blue	= 6-10	Blue Green	= 82-100
Green	= 12-20	White	= 102-270
Yellow	= 22-40		

Figure 7. Aspect map of the Middle Fork of the Feather River Watershed (N = North, S = South, E = East, W = West)

Black	= Flat	Light Green	= S
Red	= N	Dark Green	= SW
Purple	= NE	Blue	= W
Orange	= E	White	= NW
Yellow	= SE		

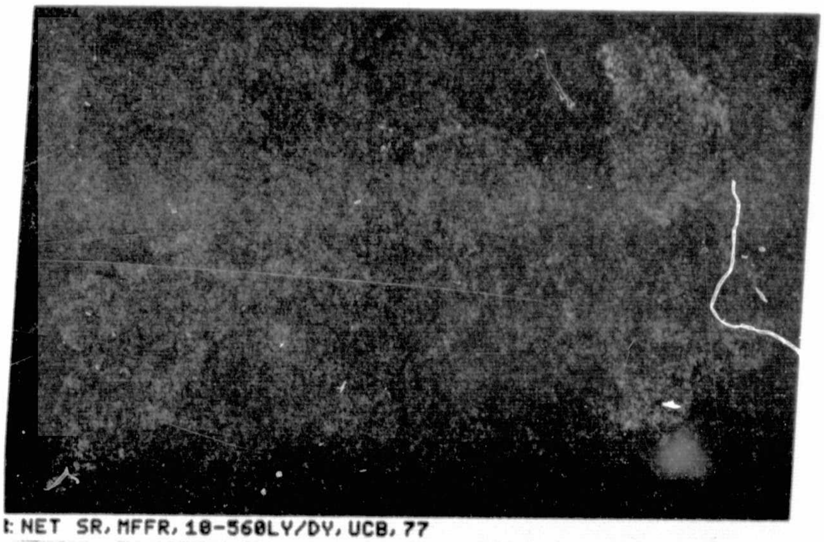

Figure 8. Areal distribution of net solar radiation in ly/day for May 16, 1975, over the Middle Fork of the Feather River Watershed.

Color		ly/day			
Dark Green	=	10-200	Yellow	=	440-450
Orange	=	210-350	Blue Green	=	460
Red	=	360-400	Light Green	=	470-500
Blue	=	410-430	Purple	=	510-560

3.200 SUMMARY AND CONCLUSIONS

Remote sensing-aided procedures have been developed by personnel of our Remote Sensing Research Program to give timely, spatial, relatively accurate, and cost-effective estimates of various parameters that are required for use in water yield forecast models. The required estimates are obtained through the use of basic multistage sampling techniques.

The input data needed in making these estimates, and requiring spatial information are provided by Landsat, by high- and low-flight aerial photography, and by ground observation. Parameters to be estimated by these remote sensing-aided procedures include snow areal extent, snow water content, solar radiation, and evapotranspiration.

The multistage sampling concept has been used successfully by RSRP in several other remote sensing research experiments involving manual and automatic data analysis. The design of this project facilitates the performance of valid statistical analyses. This is extremely important so that future results from different approaches can be analyzed with respect to one another and to prior research. Confidence intervals have been applied to all estimates discussed herein, thus providing figures relative to the accuracy of results.

Data sources that have proved to be useful in this research include the entire spectrum of environmental data gathering systems currently operating. Satellite information sources include Landsat and NOAA. The primary photographic data base consists of large to medium scale photography obtained by our group. Ground data is collected with the cooperation of both federal and state agencies such as U.S. Geological Survey, National Climatic Center, U.S. Forest Service, California Department of Water Resources, and the California Division of Forestry.

We have completed the manual analysis for snow areal extent estimation. One of the advantages of our technique versus conventional methods is that ours not only corrects the interpreter's snow areal extent classification to plot/ground values based on testing results, but also minimizes variation in final classification results between interpreters. Thus, a consistent result can be expected even through areal extent of snow estimation is performed on different areas by different interpreters. Also, the double sampling method, which in effect calibrates the more coarsely resolved Landsat-based estimates, provides a good data bank for more accurate estimation of parameters of interest.

Based on the results obtained when using the remote sensing-based techniques described above, it can be concluded that there is a substantial advantage in terms of both cost-effectiveness and precision to be gained through their use, as compared to other, conventional methods. Further investigations in automatic analysis of the areal extent of snow may be needed, in order to allow the user to make an intelligent choice as to the level of sophistication that he desires or can afford. We have also established the optimum image sample unit (grid) size for snow quantification. The complete version of a procedural manual for a remote sensing-aided system for snow areal extent estimation is described in Appendix I.

With respect to the snow water content studies that have been performed by our group to date, it is apparent that a potential cost and/or precision advantage has been gained in this area by the use of remote sensing-aided methodology. Our method utilizes data obtained through conventional ground measurement of snow courses, integrated into a double sampling framework with Landsat-derived data. Further investigations on the use of automatic analysis techniques probably would improve the precision of the snow water content estimates. Also, further refinement of physical regression models for conversion of snow cover data to snow water content indices probably would improve the accuracy of results considerably.

A remote sensing-aided system developed by RSRP for solar radiation estimation is designed to give time- and location-specific estimates on a watershed or subwatershed basis. The procedure has been applied to the Middle Fork of the Feather River Watershed for May 16, 1975. This system utilizes some constant physiographic data and some data with respect to climatic variables.

Climatic variables utilized in this system are composed of temperature, cloud cover, daylength, total incoming radiation and albedo. The values of daylength can be obtained from standard meteorological tables. Albedo can be estimated from Landsat and/or NOAA satellite data. The values of temperature can be estimated from NOAA satellite thermal data, or from spatial interpolation of ground station point temperature data, or more precisely from thermal aerial imagery. Cloud cover data may be estimated from NOAA satellites or Geostationary Operational Environmental Satellite (GOES) data. The values for total incoming radiation may be estimated either by the model developed in this system or, less precisely, by values obtained from standard meteorological data.

Areal distributions of vegetation, albedo, elevation, slope, aspect, and net solar radiation, as well as the percentage distribution of temperature, elevation and net solar radiation for the watershed covering the Middle Fork of the Feather River, are shown in this report.

We have developed models for the estimation of evapotranspiration and we are currently applying these models to the Middle Fork of the Feather River Watershed. The values obtained, area-by-area, through use of these ET models will be directly applied to the operational hydrologic model (known as the Federal-State River Forecast Center Model) that currently is being used by the California Department of Water Resources. Comparison of simulated runoff values computed after and before using ET results as an input will provide the information necessary for evaluation of ET models. As a result of our coordination with the U.C. Davis NASA-Grant participants (Algazi, et al.), the Middle Fork of the Feather River Watershed was chosen as a test area on which to apply hydrologic data for the spring of 1975.

Based on our investigation, it can be concluded that remote sensing can cost-effectively provide much of the major input data required for hydrologic models. In several specific instances we have shown that the use of our methods can help water resources managers by making available to them better water resource inventories and more accurate water-yield predictions, thereby permitting them to devise and implement better management practices. Based on such

experience, as we near the end of our research on remote sensing as applied to water supply, we are preparing and refining various Procedural Manuals, as described in Appendices I, II, III and IV. These procedures apply to our multiple resource complex inventory project outlined in Appendix V.

3.300 WORK PROPOSED FOR COMPLETING RSRP RESEARCH

The continuing aspects of our work in using remote sensing for estimating solar radiation and evapotranspiration, and in the inventory and management of the entire multiple resource complex, are as follows:

1. Completion of our evaluation of the performance of a state-of-the-art water yield forecast model, using our evapotranspiration results as one of the major inputs. This effort, which is being carried out in coordination with the U.C. Davis NASA-Grant participants has been found to be necessary to fully evaluate the water loss estimation (ET) procedures utilizing remote sensing techniques. The Federal-State River Forecast Center Model (RFC model) used by the California Department of Water Resources, continues to be examined.

2. Completion of our studies on the evapotranspiration and solar radiation models of our new watershed, covering (as it does in order to better integrate our final tests with those of the UC Davis Grant participants) the Middle Fork of the Feather River (MFFR). The models will continue to be examined, based on data acquired during the spring of 1975. Our concluding work on this MFFR watershed can be outlined as below:

a. Completion of interpolation for existing climatic data from ground meteorological stations.

b. Completion of technique development for implementation of NOAA satellite data including:
(1) Geometric correction
(2) Coordinate transformation for all arrays of data
(3) Temperature calibration
(4) Transformation of temperature data to a format compatible with our MAPIT program

c. Testing and evaluation of solar radiation models with and without data input from NOAA satellites.

d. Completion of mapping and calculation efforts with respect to all the inputs to evapotranspiration (ET) models.

e. Application of level I ET models.

3. Completion of sensitivity analyses (based on our tests with spring 1975 data) for the critical parameters in water supply models. In conjunction with the Algazi group, RSRP is developing water parameter (water loss) estimates to be included in current RFC hydrologic models. The performance change in the models with and without these remote sensing-aided estimates, and based on the U.C. Davis system will be determined. Feedback on model performance will allow modification of the remote sensing-aided water parameter estimation sampling design and methodology so as to improve hydrologic model performance.

4. Development of an automatic (computerized) system for watershed-wide integration and interpolation of point data will be furthered. This system, nearly fully developed, would estimate the distribution of point data (e.g. temperature) over the watershed of interest.

5. Preparation of a final version (as our efforts under the present grant will permit) of procedural manuals on remote sensing as an aid for watershed-wide estimation of four factors of vital importance in estimating water supply in snow-covered areas, viz. snow areal extent, snow water content, solar radiation, and water loss to the atmosphere.

6. As per agreement with our NASA monitors, we will prepare Procedural Manuals dealing with the use of remote sensing in the inventory and management of a given area's entire resource complex (i.e., its timber, forage, soils, fish, wildlife and recreational resources in addition to its water resources). While a great deal of research leading to the preparation of such manuals could be performed to advantage, we believe that we can prepare a useful document by making maximum use of remote sensing-related work that we have done during the past several years for NASA, the Department of the Interior, and the Department of Agriculture dealing with most of the above components of the total resource complex. The project outline for this study is documented as Appendix V of this report.

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APPENDIX I

Procedural Manual

REMOTE SENSING AS AN AID IN DETERMINING THE AREAL EXTENT OF SNOW

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INTRODUCTION

The term "areal extent of snow" pertains to the surface area of the terrain in a specified watershed that is covered with snow at a given time or seasonal state.

For many years the need for an improved method of estimating snow areal extent has been recognized by hydrologists and others concerned with the prediction of water runoff and the estimation of water yield, watershed-by-watershed. Among the methods showing greatest promise is the one dealt with in this Procedural Manual. That method seeks to make maximum use of modern remote sensing techniques, including those which result in the acquisition of aerial and/or space photography of the watershed at suitably frequent intervals. Because of an advantage known as the "synoptic view," it is possible on space photography, and even on high-altitude aerial photography to cover vast watershed areas with only a very few frames of photography. As will presently be seen, this advantage can be of great importance to those wishing to use such photographs as an aid in determining the areal extent of snow.

Of the several remote sensing-based techniques that have been developed for estimating snow areal extent, only two will be mentioned here since they appear to be both representative and highly promising. The first is based merely on the delineation of the apparent snowline on the photographs. The delineated portions of the photographs are then measured in such a way as to provide an estimate of the areal extent of the snow-covered area. This technique is described fully by Barnes and Bowley (1974).

A second technique has been developed which utilizes a two-stage sampling scheme to arrive at an estimate of the snow-covered area. The procedure for employing this technique is described herein. As will presently be seen, the technique employs as much ancillary (i.e., non-remote sensing-derived) information as possible to aid in the accuracy of the final estimate. Furthermore, the design of the model that is employed when this technique is used is such as to largely eliminate final estimate discrepancies, even when two or more photo interpreters are used as a team, since a statistical evaluation of each photo interpreter's results is made. The method, overall, is sufficiently simple and inexpensive to permit it to be used in addition to, rather than instead of, more conventional methods, thereby providing additional confidence in the final estimate of snow areal extent on which operational decisions must be made, in any given instance, by the hydrologist or other resource manager.

When this second method is used by a competent image analyst, in addition to his determining the total area that is covered with snow, he also derives detailed locational information of great value, i.e., he determines the exact portions of the watershed that are snow-covered and differentiates them from the snow-free areas. This can be of great advantage in relation to his desire to make accurate estimations of water yield and water runoff rates because the rate of snow depletion for a given portion of the watershed obviously is a function of its slope, aspect, vegetative cover, and other locally-variable factors.

PROCEDURE

The procedure described here for estimating areal extent of snow is based upon a two-stage analysis of remote sensing imagery. The first stage entails the use of Landsat* color composite imagery, while the second stage employs low-altitude, large-scale aerial photography. The following description provides a step-by-step guide to the use of this method in estimating the areal extent of snow:

Step 1. Prior to the start of the winter season (i.e., the season when the snowpack is to be measured) all of the projected dates when Landsat will be overflying the area of interest during the snow survey period should be systematically listed. In compiling this list one should keep in mind that there is sidelap of about 20 to 30 percent (depending upon the latitude of the area) between the 115-mile swath that is covered by Landsat on one day and that which the same vehicle covers on the following day. Therefore, this factor needs to be considered as the list is being made of all possible dates for the acquisition of Landsat imagery of the area of interest.

Step 2. During the snow-survey period, on each date when a Landsat overflight of the area of interest is about to be made under what is predicted to be suitably cloud-free conditions, by prior arrangement steps should be taken to procure nearly simultaneous low-altitude aerial color photography of preselected flight lines, thereby acquiring the previously mentioned "second stage sample." An optimum scale for such photography is approximately 1/30,000, and 35mm negative color film is preferred.

Step 3. The second stage photography procured in Step 2, above, should be promptly processed and from it standard "3R" prints (i.e., size 3-1/2" x 5") should be made.

---

*The term "Landsat" applies to various unmanned earth resources technology satellites (formerly called "ERTS"), each of which provides images of the surface of the Earth on an 18-day sun-synchronous cycle (0930 local sun time, approximately) from an altitude of approximately 570 miles and covering a swath width of approximately 115 miles.

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Step 4. As promptly as possible after the corresponding Landsat overflight has been made, and again by prior arrangement (in this case normally with the EROS Data Center at Sioux Falls, South Dakota) black-and-white MSS (multispectral scanner) transparencies should be obtained from bands 4, 5 and 7 covering the entire watershed area of interest. The standard 9"x9" transparencies produced by the EROS Data Center are preferred. In addition, either at the time when the first of this snow-season Landsat photography is being acquired, or at some earlier date, an additional summertime (snow-free) set of Landsat imagery also should be acquired for comparative analysis, as indicated below (see Step 15).

Step 5. In each instance, on the Landsat imagery that has been acquired the boundary of the watershed or other area of interest should be delineated.

Step 6. For each of the frames of Landsat imagery required in making the delineation of Step 5, a simulated color infrared color composite should be made, using the three bands (4, 5 and 7) to make a "triple exposure" on negative color film in the manner described in Appendix I-B of this Procedural Manual.

Step 7. From the resulting negative color composites, reflection prints (rather than transparencies) should be made to a size of approximately 8"x10". In those instances where more than one Landsat frame is required to cover the area of interest, the Landsat frames originally selected (and the corresponding areas copied and printed from them) should overlap each other sufficiently to provide complete coverage of the entire watershed or other area of interest.

Step 8. Either at the time when the first of the wintertime Landsat sets of imagery is obtained, or prior thereto, a set of acetate overlays each about 9"x9" in size and gridded at various intervals into squares,[1] should be prepared. In any given instance the size of the grid should be governed by time, accuracy, and cost constraints. Obviously, in most instances as grid size decreases, the accuracy, cost and time factors all increase.

Step 9. Through the use of geographic features that are readily located on Landsat imagery, each successive frame of such imagery should be indexed so that the gridded acetate overlay can be registered in exactly the same way with respect to each of the frames that cover a given area.

Step 10. Similarly, the grids, as they appear on the Landsat frames of imagery, should be transferred to the low-altitude photos (i.e., the stage two photos taken at large scale with 35mm color film) and then labelled in such a manner that any grid unit (i.e., any image sample unit) can be easily located there and readily cross-referenced to the corresponding Landsat imagery.

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1. See: Optimumization of Image Sample Unit (ISU) Size, page 3-54 .

Step 11. The indexed grids as they now appear on the low-altitude photography should be interpreted for areal extent of snow. Generally four to six snowcover classes should be used, based on the proportion of the grid that appears to be snow-covered. An example using six classes could be: Class 1, 0-9 percent; Class 2, 10-25 percent; Class 3, 25-50 percent; Class 4, 50-75 percent; Class 5, 75-90 percent; Class 6, 90-100 percent. (It has been found that, due to the large amount of detail visible on the large scale prints, it is a fairly easy task for each grid unit to be placed in a specific class with a high degree of certainty.)

Step 12. This set of classified grid units should now be divided into a training and a testing set. The training set should be located on the gridded acetate overlays to the Landsat imagery and should include a wide range of snow appearance types covering the range of snowcover classes.

Step 13. The interpretation set-up should now be constructed. It should consist of a coincident image viewing device, such as a mirror-stereoscope or a transfer scope, the set of 8"x10" Landsat summer color composite prints, for which the determination of snow areal extent is to be made, and the set of classified grid units, as seen on the low-altitude aerial photography, corresponding to the gridded winter color composite prints.

Step 14. As the detailed interpretation of the Landsat winter photos begins, one 8"x10" summer Landsat print should be placed under the stereoscope (or transfer scope) along with the corresponding scene on the gridded winter Landsat print set. The prints should be adjusted so that conjugate images can be fused by the photo interpreter (i.e., so that all common features can be made to coincide with each other, one image viewed with each eye), thus allowing the interpreter to assess both the snow areal extent and the vegetation/terrain conditions in each grid unit.

Step 15. The interpreter should next engage in the task of training himself to recognize different snowcover condition classes within grid units based on: (a) underlying vegetation/terrain features (as seen on the summer Landsat print), (b) the snowcover visible on the gridded winter Landsat print, and (c) the appearance and subsequent classification of the grid units as seen on the low-altitude aerial photography. By viewing through the coincident image device and observing how each grid unit in the training set appears during the winter and summer, and by then referring to the training set grid units on the low-altitude aerial photography, the interpreter can effectively complete this training task in very short order.

Step 16. Once trained, the interpreter should then proceed to classify each grid square (image sample unit) on the winter Landsat print

(in terms of the snow areal extent class to which it belongs) according to his synthesis of the information available as he perceives it on the summer and winter Landsat prints.

Step 17. After all of the winter dates of imagery have been classified, the interpreter's initial interpretation results are ready for the testing phase. Therefore, at this point the results of the grid classification (as made on the low-altitude aerial photography testing set) should be compared to the results obtained by the interpreter in all applicable grid units. A ratio estimator statistic, as described in detail in Appendix I-A of this Procedural Manual should then be applied. This statistic will provide the adjustment calibration necessary to correct the interpreter's initial interpretation results.

Step 18. Once the true value for the snow areal extent has been estimated using the population ratio estimator, two other statistical tests can be applied to clarify the final result. The confidence interval concept can be used to give an idea of the range of the final snow areal extent value. A Chi-square test can be applied to test the snowcover class width selection. Both of these tests are discussed in detail in Appendix I-A.

Note: It is apparent from the foregoing that, even if this procedure is highly successful, its end product is merely an accurate determination of the areal extent of snow, together with an accurate delineation of each portion of the watershed area according to the snowcover class to which it belongs. This is an essential step leading to a prediction of water runoff and the estimation of water yield. The remaining steps are discussed in other procedural manuals.

APPENDIX I-A

A SPECIFIC CASE STUDY

The following case study describes uses that our RSRP personnel have made of the foregoing procedure for the Feather River Watershed, California.

On April 4, 1973 the majority of the Feather River Watershed (located in the central Sierra Nevada Mountains, California) was imaged in a virtually cloud-free condition by the Landsat satellite. In order to document the existing ground conditions in greater detail than that provided by the satellite imagery, a photographic mission was flown over the watershed on April 6, 1973. Four transects were flown using a motorized 35mm camera to acquire photography at a scale of approximately 1:30,000 on the negative (Figures I-3 and I-4).

Landsat imagery from August 13, 1972 was chosen for use as the vegetation/terrain base for the snowpack analysis procedures. The August 13 and the April 4 Landsat images of MSS bands 4, 5, and 7 were photographically combined to produce simulated color infrared enhancements (Figures I-3 and I-4) on color negative film using the previously mentioned technique (Appendix I-B).

The simulated color infrared enhancement of the August 13, 1972 Landsat scene was photographically reproduced to give a 16" x 20" color print of approximately 1:250,000 scale. The April 4, 1973 Landsat color infrared enhancements were enlarged to precisely the same scale as the August 13, 1972 imagery and printed to give overlapping 8" x 10" prints.

An acetate grid (each grid block equalling approximately 2,000 meters on a side at a scale of approximately 1:250,000) was attached to the vegetation/terrain Landsat image. The grid blocks, termed image sample units (ISU), were transferred to the large scale photography where applicable. The image sample units on the large scale aerial photography were coded as shown in Table I-1.

Table I-1

Snowcover Condition Classes Used for Areal Extent of Snow Estimation

Code	Snowcover Class	Midpoints
1	No snow present within ISU	0
2	0-20% of ISU covered by snow	.10
3	20-50% of ISU covered by snow	.35
4	50-98% of ISU covered by snow	.74
5	98-100% of ISU covered by snow	.99

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The interpreter then engaged in the training phase to familiarize himself with the imagery and image classification technique. Once trained, the interpreter proceeded to classify all the image sample units on the 8" x 10" Landsat color print for the winter dates. A more detailed description of this process will be found in the Procedural Manual.

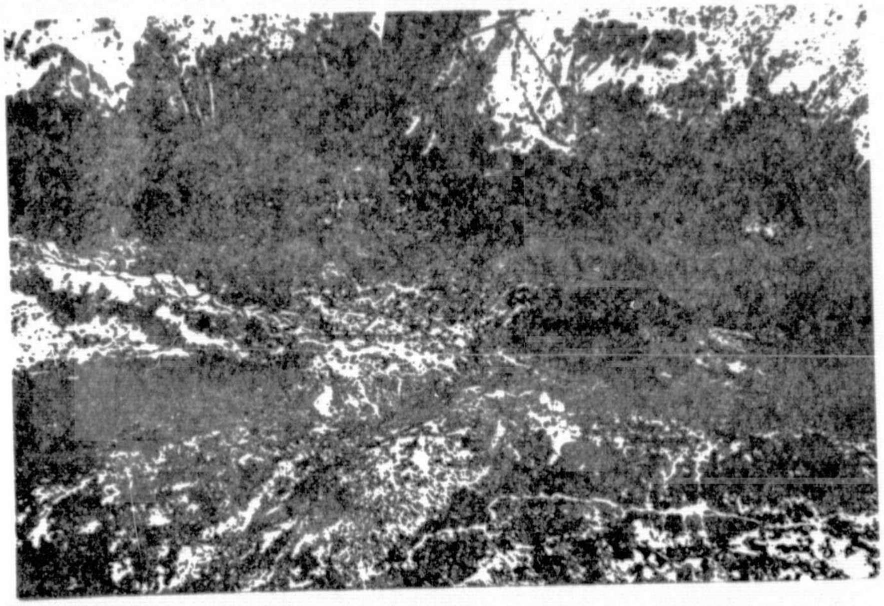

FIGURE I-1

Low altitude aerial photographs of the snowpack taken from a light aircraft using a 35 mm camera. The scale of the negative is approximately 1:30,000. The grid shown on the photograph represents an image sample unit, (ISU), also located on the Landsat color composite imagery (see Figure I-4). The image sample unit shown represents a snowcover class of 3 (See Table I-1).

FIGURE I-2

Low altitude aerial photograph of the snowpack similar to Figure I-1 however representing a snowcover class of 4 (See Table I-1).

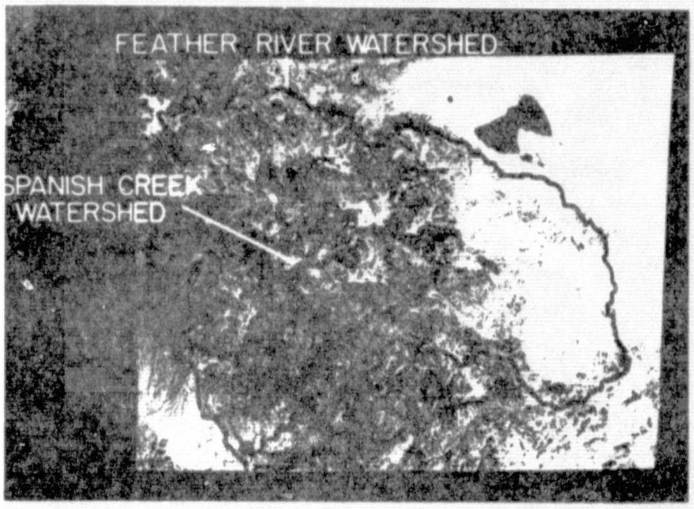

FIGURE I-3

August 13, 1972 Landsat color composite image showing the Feather River and the Spanish Creek Watersheds.

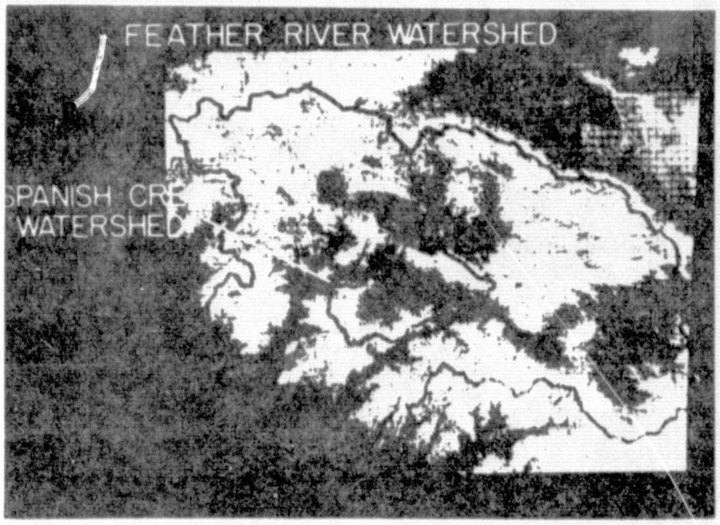

FIGURE I-4

April 4, 1973 gridded Landsat color composite image showing the Feather River and Spanish Creek Watersheds. The grids define the image sample units, each being approximately 400 hectares in size.

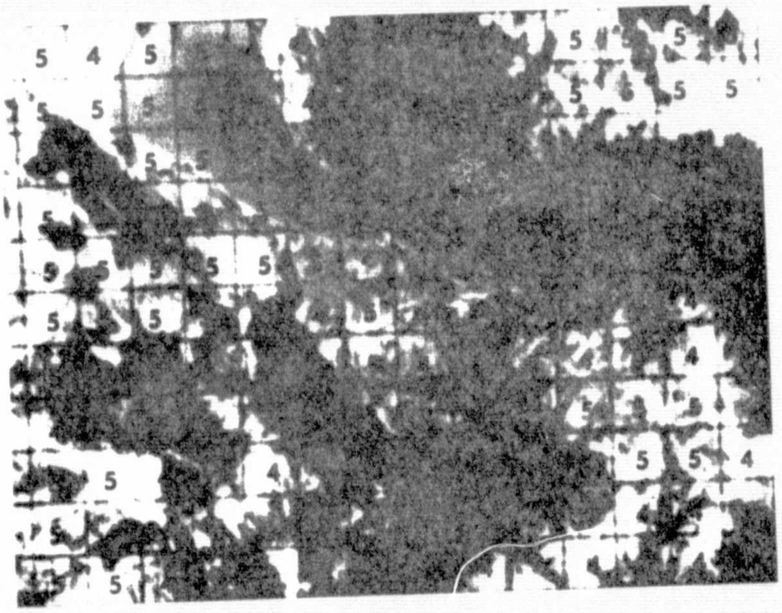

FIGURE I-5

A portion of the April 4, 1973 Landsat color composite image showing the snowcover class interpretations on an image sample unit basis.

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The classified imagery was then subjected to statistical analysis. The following are the results from the April 4 Landsat areal extent of snow analysis.

	Snowcover (Condition) Class				
	1	2	3	4	5
Total number of ISU's classified per class	403	289	214	453	859

To derive the approximate number of hectares in each class, the image sample unit totals per class were multiplied by the number of hectares per image sample unit (400) with the results indicated below:

	Snowcover (Condition) Class				
	1	2	3	4	5
Hectares	$.161 \times 10^6$	$.116 \times 10^6$	$.856 \times 10^5$	$.181 \times 10^6$	$.344 \times 10^6$

Then to establish the approximate amount of actual snow-covered area per class, the number of hectares/class were multiplied by the snowcover class midpoints (from Table 1) for each class, as indicated below in the following tabular summary:

	Snowcover (Condition) Class				
	1	2	3	4	5
Snowcover condition class midpoint	0	.10	.35	.74	.99
Hectares of snow per class	0	$.116 \times 10^5$	$.300 \times 10^5$	$.134 \times 10^6$	$.340 \times 10^5$

By adding the "hectares of snow per class" values, the "total surface area of snow" in hectares was established. Thus for the April 4, 1973 Landsat date the estimate of snow areal extent was found to be 515,772 hectares. This value, however, may be biased by any errors which occurred during the classification of the Landsat image sample units for snow areal extent. The uncorrected areal extent of snow estimate can be "corrected" by comparing the interpreter classification results with a series of preselected, preclassified image sample units, chosen for testing purposes from the large scale aerial photographs.

Interpretation results not falling in a given snowcover condition class for both the large scale aerial photographic and Landsat image data represent a misclassification of image sample units by the interpreter (Table I-2). Thus it can be seen that 13 out of a possible 80 image sample units were misclassified. This misclassification error can then be represented by a statistic, the population ratio estimator (Cochran, 1959), which will be used to correct the initial areal extent of snow estimate of 5.1582×10^5 hectares derived from the Landsat image classification.

The statistical approach is defined as follows:

(Equation 1.0) $\hat{Y}_r = X\hat{R}$ = the final, corrected areal extent of snow estimate

(Equation 1.1) where: $X = \sum_{j=1}^{N} X_j$ = the uncorrected Landsat areal extent of snow estimate

given that: X_j = the Landsat interpretation estimate of snow areal extent, per image sample unit, by snowcover class

j = the index for all Landsat image sample units

N = the total number of Landsat image sample units classified for snow areal extent

(Equation 1.2) where: $\hat{R} = \overline{Y} \div \overline{X}$ = the population ratio estimator

(Equation 1.3) given that: $\overline{Y} = \left(\sum_{i=1}^{n} y_i\right) \div n$ = the average snow areal extent value for the large scale photographic image sample unit estimates

(Equation 1.4) $\overline{X} = \left(\sum_{i=1}^{n} x_i\right) \div n$ = average snow areal extent value for the Landsat image sample unit estimates

and that: n = the total number of image sample units used in the testing phase

i = sampling index

y_i = large scale photography snow areal extent estimate for image sample unit i

x_i = Landsat snow areal extent estimate for image sample unit i

Since the uncorrected Landsat areal extent of snow estimate (X) has been calculated to be 5.158×10^5 hectares, the value for the population ratio estimator, R, must be determined to solve for the final, corrected Landsat areal extent of snow estimate, $\hat{Y}_r$, (from the equation $\hat{Y}_r = X\hat{R}$). Table I-3 represents an expanded version of Table 2 designed to facilitate the calculation of the population ratio estimator, $\hat{R}$. The table has been enlarged to include listings of snowcover condition class/image sample unit, specific large scale photography estimates of snow areal extent, and Landsat areal extent of snow estimates.

y_u = large scale aerial photography estimate of snow areal extent per image sample unit by snowcover condition class (in hectares)

$$= \left[\begin{matrix}\text{snowcover condition class}\\ \text{midpoint}\end{matrix}\right] \left[\begin{matrix}\text{number of hectares}\\ \text{per image sample unit}\end{matrix}\right]$$

and; x_u = Landsat snow areal extent estimate per image sample unit by snowcover condition class (in hectares)

$$= \left[\begin{matrix}\text{snowcover condition class}\\ \text{midpoint}\end{matrix}\right] \left[\begin{matrix}\text{number of hectares}\\ \text{per image sample unit}\end{matrix}\right]$$

f_u = image sample unit interpretation frequencies

u = index for table containing the results of the testing phase

Additionally,

n = the number of image sample units used in the testing phase, i.e.,

(Equation 1.5)
$$n = \sum_{u=1}^{1} f_u = 80$$

where: u = index for Tables I-2 and I-3

and k = the number of interpretation result blocks in Tables I-2 and I-3 = 11.

$\hat{R}$, the population ratio estimator, can now be calculated by solving for $\overline{Y}$ and $\overline{X}$ from the data presented in Table I-3. Thus, if

(Equation 1.6)
$$\sum_{i=1}^{n} y_i = \sum_{u=1}^{k} f_u\, y_u$$

(Equation 1.7) and $$\sum_{i=1}^{n} x_i = \sum_{u=1}^{k} f_u \, y_u$$

then $$\overline{Y} = \sum_{i=1}^{n} y_i \div n$$ (Equation 1.3)

(Equation 1.8) $$= \sum_{u=1}^{k} f_u \, y_u \div n$$ (from Equation 1.6)

(Equation 1.9) $$= \sum_{u=1}^{k} f_u \, y_u \div \sum_{u=1}^{k} f_u$$ (from Equation 1.5)

and $$\overline{X} = \sum_{i=1}^{n} x_i \div n$$ (Equation 1.4)

(Equation 2.0) $$= \sum_{u=1}^{k} f_u \div n$$ (from Equation 1.7)

(Equation 2.1) $$= \sum_{u=1}^{k} f_u \, x_u \div \sum_{u=1}^{k} f_u$$ (from Equation 1.5)

Therefore (from Table I-3 and Equations 1.9 and 2.1):

$$\overline{Y} = \frac{(0)(6)+(40)(1)+(40)(10)+(296)(1)+(40)(2)+(140)(6)+(296)(2)+(140)(1)+(296)(12)+(296)(6)+(396)(33)}{6+1+10+1+2+6+2+1+12+6+33}$$

$$= \frac{20784}{80}$$

$$= 259.80$$

and

$$\overline{X} = \frac{(0)(6)+(0)(1)+(40)(10)+(40)(1)+(140)(2)+(140)(6)+(140)(2)+(296)(1)+(296)(12)+396(6)+396(33)}{6+1+10+1+2+6+2+1+12+6+33}$$

$$= \frac{21132}{80}$$

$$= 264.15$$

Consequently, the population ratio estimator (Equation 1.2) is calculated to be:

$$\hat{R} = \overline{Y} \div \overline{X} \qquad \text{(Equation 1.2)}$$

$$= 259.80 \div 264.15$$

$$= .9835$$

Finally, to solve for $\hat{Y}_r$ (the final, corrected areal extent of snow estimate), the population ratio estimate, $\hat{R}$, is multiplied by the uncorrected Landsat areal extent of snow estimate, X (Equation 1.0). Thus,

$$\hat{Y}_r = X\hat{R} \qquad \text{(Equation 1.2)}$$

$$= (\ 515{,}772\ )\ (.9835) \text{ hectares}$$

$$= 507{,}278 \text{ hectares}$$

Once the actual areal extent of snow has been estimated, $\hat{Y}_r$, it may be useful to know where the true value for the areal extent of snow lies. The confidence interval is useful for this purpose. The statistical approach is as follows, using the 95% level of confidence as an example:

Y_r = the true value for the areal extent of snow

The confidence interval around Y_r can be expressed as the probability that

(Equation 2.2) $$\left[\hat{Y}_r - t_{n-1,\ .025}\sqrt{V(\hat{Y}_r)} \leq Y_r \leq \hat{Y}_r + t_{n-1,\ .025}\sqrt{V(\hat{Y}_r)}\right] = .95$$

(Equation 2.3) where $$V(\hat{Y}_r) = \frac{N(N-n)}{n(n-1)}\left[\sum_{i=1}^{n} y_i^2 + \hat{R}^2 \sum_{i=1}^{n} x_i^2 - 2\hat{R}\sum_{i=1}^{n} x_i\, y_i\right]$$

= sample variance

where $$\sum_{i=1}^{n} Y_i^2 = \sum_{i=1}^{k} f_u(Y_u^2)$$

and $$\sum_{i=1}^{n} X_i^2 = \sum_{i=1}^{k} f_u(X_u^2)$$

A summary of all the major results from the statistical analysis described previously for the April 4, 1973 snow analysis date is contained in Table I-4.

The final statistical test that was employed in this analysis was used to determine the suitability of the snowcover condition class widths as selected from step 11 in the procedure and Table 1. This test was to determine if the values in the snowcover classes from the Landsat image data came from the same statistical probability distribution as the values in the snowcover classes from the large scale aerial photographic data. If they came from the same distribution it could be expected that the areal extent of snow estimation procedure would provide good results. If these indicated that the two data sets came from different distributions, then new class widths should be selected and the areal extent of snow estimation procedure should be rerun. To perform such probability distribution "likeness tests," a Chi-square statistic was used:

(Equation 2.4)
$$x^2 \sim \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

where O_i = the observed values

E_i = the expected values

k = the number of snowcover condition classes

i = index.

The values in the snowcover classes from the large scale photo data were designated as the <u>expected</u> values (E_i), since they were assumed to be "ground truth." The values in the snow cover classes from the Landsat image data were designated as the <u>observed</u> values (O_i).

The results of the Chi-square test for the April, 1973 statistical testing data (Table I-2) are shown in Table I-5. The results indicate that the two data sets do come from the same statistical probability distributions; thus it can be assumed that the snowcover class widths used for the areal extent of snow analysis are adequate.

Table I-2

Interpretation results of the testing phase, areal extent of snow estimation for the April 4, 1973 Landsat and April 6, 1973 large scale aerial photographic data.

		Large Scale Aerial Photographic Data				
		Snowcover Condition Class				
		1	2	3	4	5
Landsat Image Data, Snowcover Condition Class	1	6	1			
	2		10		1	
	3		2	6	2	
	4			1	12	
	5				6	33

Key to Table I-2: $\boxed{f_u}$

where: f_u = Image sample unit interpretation frequencies

u = Index for the table.

Table I-3

Interpretation results of the testing phase, areal extent of snow estimation for April 4, 1973 Landsat and April 6, 1973 large scale aerial photographic data. Also included is a listing of uncorrected large scale aerial photographic and Landsat image estimates of snow areal extent per image sample unit by snowcover class.

Landsat Image Data — Snowcover Condition Class	Large Scale Aerial Photographic Data — Snowcover Condition Class: 1	2	3	4	5
1	0 0 6	40 0 1			
2		40 40 10		296 40 1	
3		40 140 2	140 140 6	296 140 2	
4			140 296 1	296 296 12	
5				296 396 6	396 396 33

Key to Table I-3:

	y_u
x_u	f_u

where: x_u = Landsat snow areal extent estimate per image sample unit by snowcover condition class (in hectares)

y_u = Large scale photography snow areal extent estimate per image sample unit by snowcover condition class (in hectares)

f_u = Image sample unit interpretation frequency

u = Index for the table.

Table I-4

Summary of Statistical Results
Areal Extent of Snow Estimation
April 4, 1973

Landsat estimate of the areal extent of snow (in hectares)	X	515,772
Population ratio estimator	$\hat{R}$	.9835
Estimate of the true areal extent of snow (in hectares)	$\hat{Y}_r$	507.278
Standard deviation of the areal extent of snow estimate (in hectares)	$\sqrt{V(\hat{Y}_r)}$	12,659.29
Confidence interval (95%) around the true value for the areal extent of snow (in hectares)		$482,040 \leq Yr \leq 532,517$
Total number of image sample units inventoried on the Landsat imagery	N	2,218
Average surface area of an image sample unit (in hectares)		400
Total number of hectares inventoried		887,200
Total number of image sample units sampled for the statistical testing procedure	n	80

Table I-5

Chi-square Test for April 4, 1973 Data

Null Hypothesis: Ho: The observed values (O_i) come from the same distribution as the expected values (E_i)

Alternative Hypothesis: Hi: The observed values do not come from the same distribution as the expected values

Significance Level: 5%

Test Statistic under the Null Hypothesis: $\sum_{i=1}^{k} \frac{(O_i-E_i)^2}{E_i} \sim X^2_{k-1}$;

where k-1 = the degrees of freedom

Full Class Data Summary

Class	O_i	E_i	$\frac{(O_i-E_i)^2}{E_i}$
1	7	6	.1667
2	11	13	.3077
3	10	7	1.2857
4	13	21	3.0476
5	39	33	1.0909

$$\sum_{i-1}^{k} = 5.8992$$

Conclusion: The null hypothesis is accepted since the calculated value of 5.8992 is less than the table value of 9.49.

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APPENDIX I-B

OPTIMAL IMAGE SAMPLE UNIT SIZE ESTIMATION

The operational application of the image sample unit areal extent of snow estimation technique is heavily dependent on the size of the image sample unit used.

It was expected that the smaller the ISU size the smaller the standard deviation (and variance) of the corrected areal extent of snow estimate. Conversely, as the size of the ISU's decreased, it was suspected that interpretation time (also known as cost!) would increase. In an effort to give prospective users a starting point when deciding on what image sample unit size to use, a simple test was developed to find some optimal image sample unit size (i.e. minimized standard deviation and interpretation time). The test would compare interpretation time and standard deviation of the corrected areal extent of snow estimate for three different image sample unit sizes. One interpreter was used throughout the test to minimize - or at least standardize - bias in the final results.

Three image sample unit sizes (204, 459, and 815 hectares squared each) were used on a single Landsat winter date. Interpreter training, classification, and testing were carried out as described in steps 15, 16 and 17.

The results of the areal extent of snow estimation to standard deviation and interpretation time versus image sample unit size are summarized in Table I-6.

Table I-6. Summary of ISU Optimumization Data

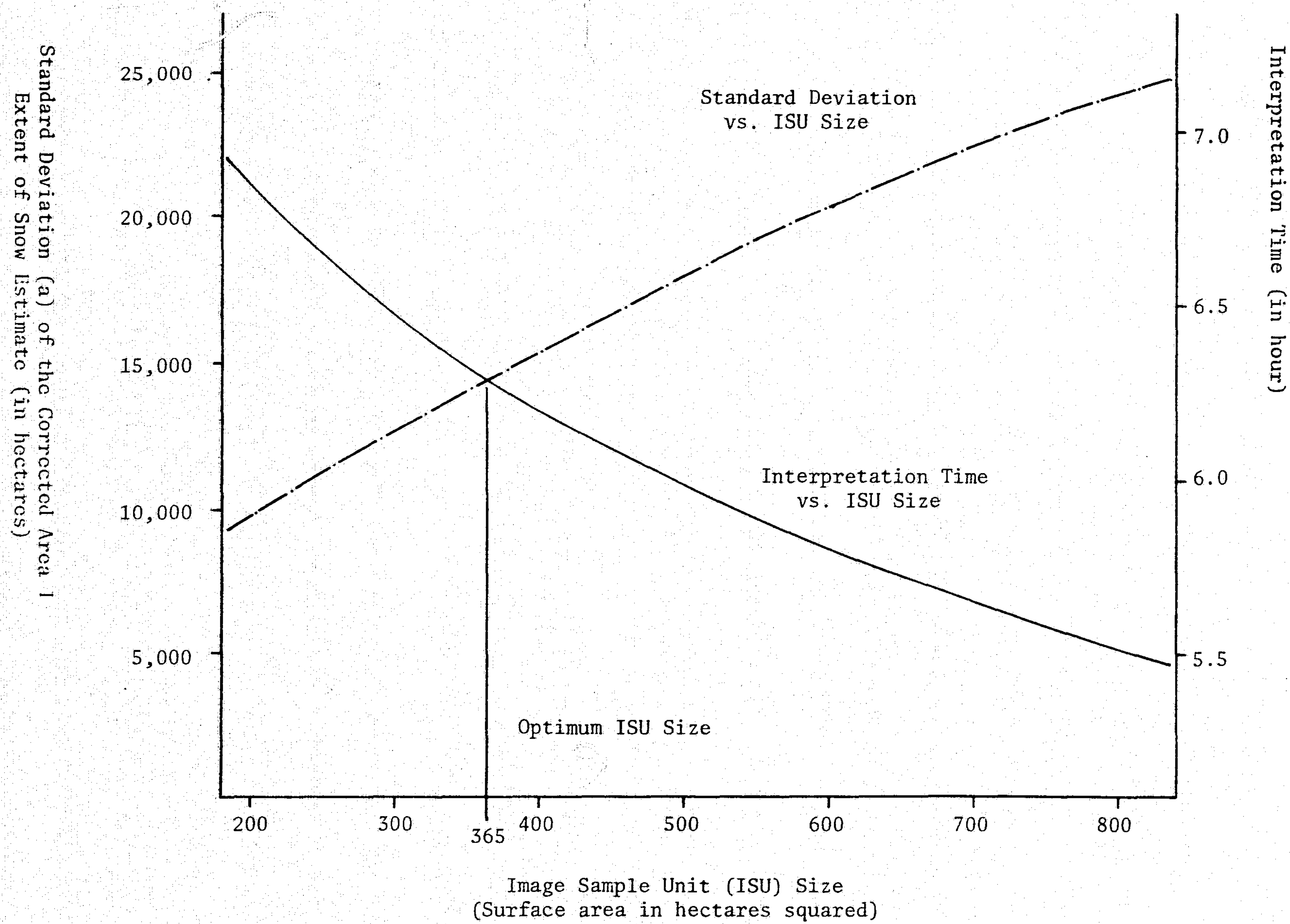
Image Sample Unit Size (in hectares squared)	Standard Deviation of the estimate (in hectares)	Interpretation Time (in hours)
204	9,981.36	6.75
459	16,864.54	6.00
815	24,439.40	5.50

As expected standard deviation decreases and interpretation time increases with image sample unit size. By plotting the data it was determined that an image sample unit size of 365 hectares squared was the point where both standard deviation and interpretation were minimized as shown in Figure I-6.

It should be noted that the image sample unit size of 365 hectares squared is to be considered a maximum size for two reasons:

(1) The interpreter who analyzed the three image sample unit sizes was previously inexperienced in this type of interpretation. The largest ISU size was interpreted first and the smallest last. It can be expected that the interpretation times for each succeeding ISU size was reduced due to the experience gained on the operation of the interpretation system design. Thus, it seems reasonable that as more experience is gained, the intepretation time for any ISU size would be reduced, lowering the interpretation time versus ISU size curve. Consequently, the value of 365 hectares squared for an "optimal" ISU size could conceivably be reduced by increasing interpreter experience.

(2) While the results illustrated in Figure I-6 indicated an optimal ISU size for minimizing standard deviation and interpretation time, the image sample unit size may de decreased even further if more time can be spent in the interpretation phase.



DETERMINATION OF OPTIMAL ISU SIZE
Figure I-6

APPENDIX I-C

THE PHOTOGRAPHIC CONSTRUCTION OF LANDSAT COLOR COMPOSITE IMAGERY

INTRODUCTION

The value of color composites has long been recognized as an aid to the interpretation of Landsat imagery. The technique described in this technical brief demonstrates how Landsat color composite imagery can be constructed from Landsat positive black-and-white transparencies conveniently and inexpensively.

COLOR COMPOSITE THEORY

Typical color reversal and color negative films consist basically of three light sensitive layers. These layers react individually to blue, green, and red light, each layer corresponding to a particular dye, dependent upon film type, as indicated below:

Light Sensitivity	Color reversal film Dye layers activated	Color negative film Dye layer activated
Red	Yellow and Magenta	Cyan
Green	Yellow and Cyan	Magenta
Blue	Magenta and Cyan	Yellow

If, for instance, color negative film is exposed to blue light, the blue sensitive layer of the film is activated while the other layers remain unaffected. This blue-sensitive layer corresponds to a final yellow dye image and hence the results will appear yellow on the negative.

When color reversal film is exposed to blue light, the blue sensitive layer of the film is activated; however, during processing the two remaining sensitivity layers corresponding to the magenta dye (green sensitive) and the cyan dye (red sensitive) are either chemically or mechanically exposed. The originally exposed blue sensitive layer becomes non-functional and the resulting image appears blue due to the combination of magenta and cyan dyes. The reactions of color reversal and negative film to red and green light can be explained similarly since red is produced by a combination of yellow and magenta dyes and green is produced by a combination of cyan and yellow dyes.

The photographic construction of Landsat color composites relies on the three-layer sensitivity of color film and on the different densities of any given feature as it appears on the various Landsat black-and-white bands. Each of the different Landsat black-and-white bands chosen to make the color composite is photographically copied onto the same sheet (or frame) of color film, each band through a different colored filter (in essence a multiple exposure). Figure I-7 illustrates the set-up used to produce Landsat color composites. Depending on which filter is used with each band of imagery different color renditions may be produced, hopefully enhancing different features.

MATERIALS AND EQUIPMENT

LANDSAT BLACK-AND-WHITE IMAGERY

The construction of Landsat color composites commonly uses Multispectral Scanner (MSS) imagery of bands 4, 5, and 7, usually in the 9½ inch positive transparency form (although the 70 millimeter positive transparencies may also be used). MSS Band 6 is also used for some composites as well as available Return Beam Videcon (RBV) positive imagery. Furthermore, just as a color composite can be formed by combining bands of imagery acquired on a single date, so it also can be formed by combining several dates of imagery acquired in a single band, or any combination of multiband/multidate images.

FILTERS

Eastmak Kodak Wratten filters are suggested for use in the construction of color composites due to their optical quality and the large variety of colors and sizes available. To produce a simulated false-color infared color composite image (Figures I-3 & I-4), Wratten filter number 25 (tricolor red), 47B (tricolor blue), and 58 (tricolor green) can be used.

FILTER RELATED ACCESSORIES

Eastmak Kodak filter frames provide a convenient way to mount the Wratten filters. The filters so mounted can be easily inserted into a commercially available filter holder which mounts, via adapters, to the filter-threaded receptacle in the front of most enlarging lenses.

PHOTOGRAPHIC LIGHT SOURCE

The light source is used to provide the light which will be transmitted through the Landsat bands during the exposure process. Basically, the light source may be of two common types; incandescent or flourescent and electronic strobe. Incandescent or flourescent illumination in the form of a "light table" may be the most convenient form to use initially. One of the problems encountered with using a light table is its relatively low light output, necessitating long exposures times. One way of countering this is by using an electronic strobe light box which could give decidely greater light output and thus shorter exposures.

REGISTRATION SHEET

The registration sheet is used to register the individual Landsat bands with respect to one another. It also serves as a convenient base for introducing grids, watershed boundaries or other data directly on the color composite. The material used for the registration base should be translucent (frosted preferably), dimensionally stable and have a surface amenable to scribing.

SCRIBING TOOLS

The scribing tools consist of a scriber and a metal straight edge. The scriber can be constructed by inserting a drafting compass needle in an engineering drafting pencil while the metal straight edge may simly be a metal engineering scale. The scribing tools are used to transfer the Landsat registration marks onto the registration sheet.

CAMERA SYSTEM

A large variety of cameras and related accessories ranging in format from 35 millimeter to much larger image sizes can be used to construct Landsat color composites. The only requirement is that the camera be capable of making accurate multiple exposures on a single sheet or frame of film. The most convenient camera used to develop this system was found to be a type of copy camera which utilizes a leaf shutter system allowing as many exposures as desired on a single sheet or frame of film. A camera system of this type is desirable due to its ability to accept film formats from 35 millimeters to 4 x 5 inches.

The camera lens used for making color composites should be of very high quality. Since the construction of color composites utilizes most of the light-sensitive spectral range of conventional color film, the lenses used should be color corrected. The lenses should be of very high uniform edge-to-edge resolution and contrast to assure that no information is lost throughout the image area.

EXPOSURE METER

An exposure meter should be used to determine how much exposure should be given to each of the Landsat black-and-white images in making the color composite. The meter used should have a locking needle, a wide sensitivity range and a narrow acceptance angle so that selective area measurements can be made.

FILM TYPES

If reflection prints are to be made of the color composite, it is most convenient to use a fine grain negative color film such as Kodak Vericolor II Type S. If positive color transparencies are desired (e.g. for projection purposes) the use of either Kodachrome or Ektachrome film is appropriate, depending on the film format used.

PROCEDURE

The following step-by-step description will detail the procedure used to construct a Landsat color composite.

Step 1. Tape one band of a Landsat black-and-white set of imagery for a specific date to a light table in proper viewing position.

Step 2. Tape a sheet of the registration base material over the Landsat image so that the four registration marks (+) in the corners of the Landsat image are completely covered by the overlying sheet.

Step 3. Transfer the registration marks to the registration base material using the scriber and the metal straight edge. The scribed line should be narrow in width and extend beyond the actual Landsat registration marks to facilitate the actual registration process.

Step 4. The registration sheet should be labeled with the latitude/longitude and date of the Landsat imagery from which it was made. This information is placed on the same edge as observed on the Landsat image below so that the Landsat black-and-white bands may be oriented correctly during the registration process.

Step 5. The completed registration sheet is removed and placed in proper position on the light table or flash box and taped down.

Step 6. One of the Landsat bands to be used for making the composite is taped down in register over the registration sheet. The registration marks and the information line are used to register and orient the two, relative to one another.

Step 7. The camera system is focused upon this registered image and locked into position.

Step 8. An exposure measurement of the Landsat band is then made on the ground glass focusing screen of the camera with the lens set at a fixed aperture, usually maximum. This reading is recorded. The other Landsat bands to be used are then placed one at a time on the registration sheet with the image projected onto the focusing screen and the exposure measurement for each is recorded again at the same fixed aperture.

Step 9. The exposure measurements for the Landsat bands are averaged and refered to exposure graphs (which are explained in the next section).

Step 10. The camera/lens exposure controls are then set according to the exposure graphs.

Step 11. The film on which the composite is to be made is then loaded in the camera.

Step 12. One at a time, the Landsat bands are placed on the registration sheet and exposed through the appropriate filter. The film is not advanced or removed until all exposures have been made.

Step 13. The film is then processed normally yielding the final color composite.

EXPOSURE DETERMINATION

In determining the proper exposure to give each of the Landsat black-and-white images the separate bands are assumed to be matched separation positives. The actual deviation from this assumption is generally so slight that it may be ignored in most if not all cases.

Since no two light source systems developed to construct Landsat color composite imagery will have equal light outputs, the graph used to determine proper exposure must be empirically established. The following describes the determination of the exposure graph necessary for proper exposure calculation. Since each exposure graph can be calculated for one particular color composite type (i.e., band/filter combination) only, the following description will deal with the construction of a simulated false color infrared composite. To make this particular rendition Landsat band 7 is exposed through a Wratten 25 (Red) filter, band 5 through a Wratten 58 (Green) filter and band 4 through a Wratten 47B (Blue) filter.

To empirically determine the exposure graphs for the various band/filter combinations, a series of color composites are constructed at different overall exposures. Each series of color composites has exposure values measured for each band as per step 8 under "procedures". The values measured are averaged for each set and then plotted versus the actual overall exposure found to give an acceptable color composite. All light measurement values are taken with the lens set at a fixed aperture. This aperture will always be used for the through-the-lens exposure measurements of each band. This is necessary to provide a consistent index system for reference to the exposure graphs.

The averaged exposure measurements taken from the individual Landsat bands are plotted on the x-axis versus Exposure Values (EV) on the y-axis. EV refers to equal light intensities; hence equal combinations of shutter speed and aperture which yield the same exposure to the film. For example, EV 13 equals 1/30 second at f/15, 1/60 second at f/11, 1/125 second at f/8, 1/250 second at f/5.6, etc. Figure I-7 illustrates the appearance of such an exposure graph.

Due to the different optical densities of the filters used to construct a color composite, different exposures are needed for each band/filter combination. These different densities can be refered to as filter factors. The filter factor for a given filter changes with the film type as well as the light source; consequently filter factors must be calculated for each film type/light source combination. One practical way of calculating specific filter factors is to photograph a transparent gray scale through each of the filters for which the filter factor is to be determined. These will produce individual exposures through the filters onto color film, either positive or negative. Several exposures are taken through each filter, advancing or changing the film after each exposure. All exposures must be recorded for the final determination of the filter factors. For each filter an exposure is found which best reproduces the gray scale (i.e. all gray levels are

clearly distinguishable from each other) by examining the color film. In all cases each individual gray level should have the same optical density for all of the filter types used. This is best done through the use of a densitometer but can be done visually if necessary. A comparison of the exposures used for the various filters to obtain equal densities gray level-by-gray level, will give the filter factors for each filter. These filter factors may then be translated into EV's to give the relative exposure differences for the filters used.

To establish the exposure graphs for the various band/filter combinations, a series of color composites are constructed, all at different overall exposures. Each composite so constructed must have the filter factors (in terms of individual exposure differences) included. If, for example, for a specific film/light source combination, it is determined that a Wratten 47B filter requires 1 EV more exposure than a Wratten 58 filter, (which requires itself ½ EV more exposure than a Wratten 25 filter to obtain equal density levels) then a series of exposures can be made using these differences. For the first composite the overall exposure might be EV13 through the Wratten 47B filter, EV 14 through the Wratten 58 filter, and EV 14.5 through the Wratten 25 filter. For the second composite overall exposure might be EV14 through the Wratten 47B filter, EV 15 through the Wratten 58 filter, and EV 15.5 through the Wratten 25 filter and so on. Since the individual filters require different but equal relative exposure differences maintained during the construction of the composites, color balance is kept stable, but overall composite density is not. Thus the best composite density from this series of different overall exposures can be determined. By plotting the exposures used for each filter in the best composite constructed, one group of points may be plotted on the exposure graph for this particular band/filter combination. Once two groups of points, each representing a good color composite overall exposure for a specific band/filter combination have been plotted, the graph can be completed.

CONCLUSIONS

Several critical points are worth mentioning again to assure that the color composites are correctly constructed:

1. During the actual photographic construction, several exposures are made on the <u>same</u> sheet or frame of film; the film is not removed or advanced during these exposures.

2. All exposure measurement values of the various bands are made through the camera/lens assembly on the ground glass using a fixed aperture. This aperture may change depending upon the actual responses of the various bands during the copying process.

3. The individual exposure measurements of the bands to be used are mathematically averaged and then referred to the exposure graph for the exposure setting of each band/filter combination.

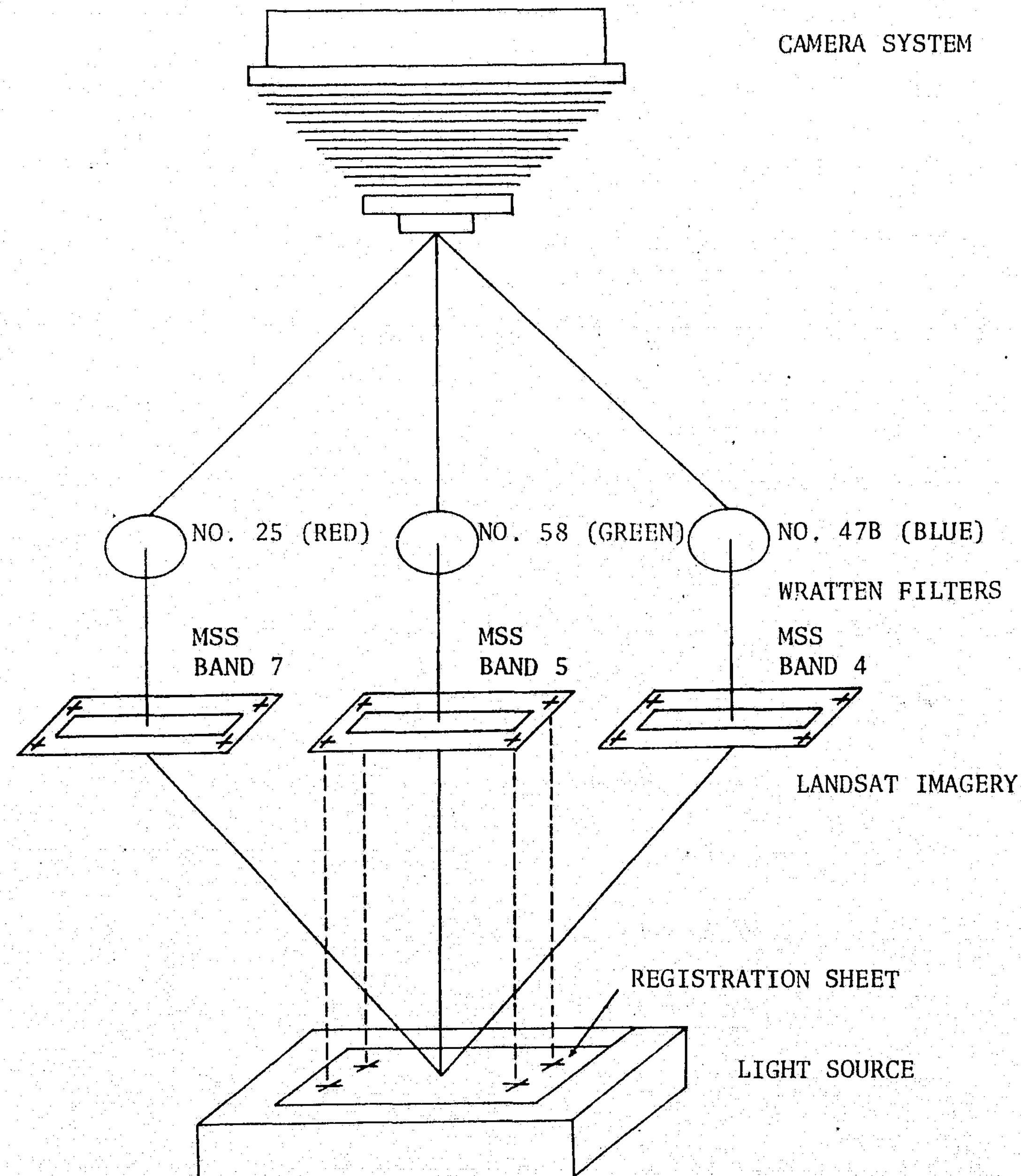


Figure I-7. This schematic diagram illustrates the photographic technique for constructing color composite images. A camera, color film, colored filters, LANDSAT imagery, a registration sheet and a light source are employed. Note that all three bands are placed separately on the registration sheet for copying. The band/filter combinations shown in the diagram above are used to produce simulated false color infrared composites. Different band/filter combinations will produce differently colored composites.

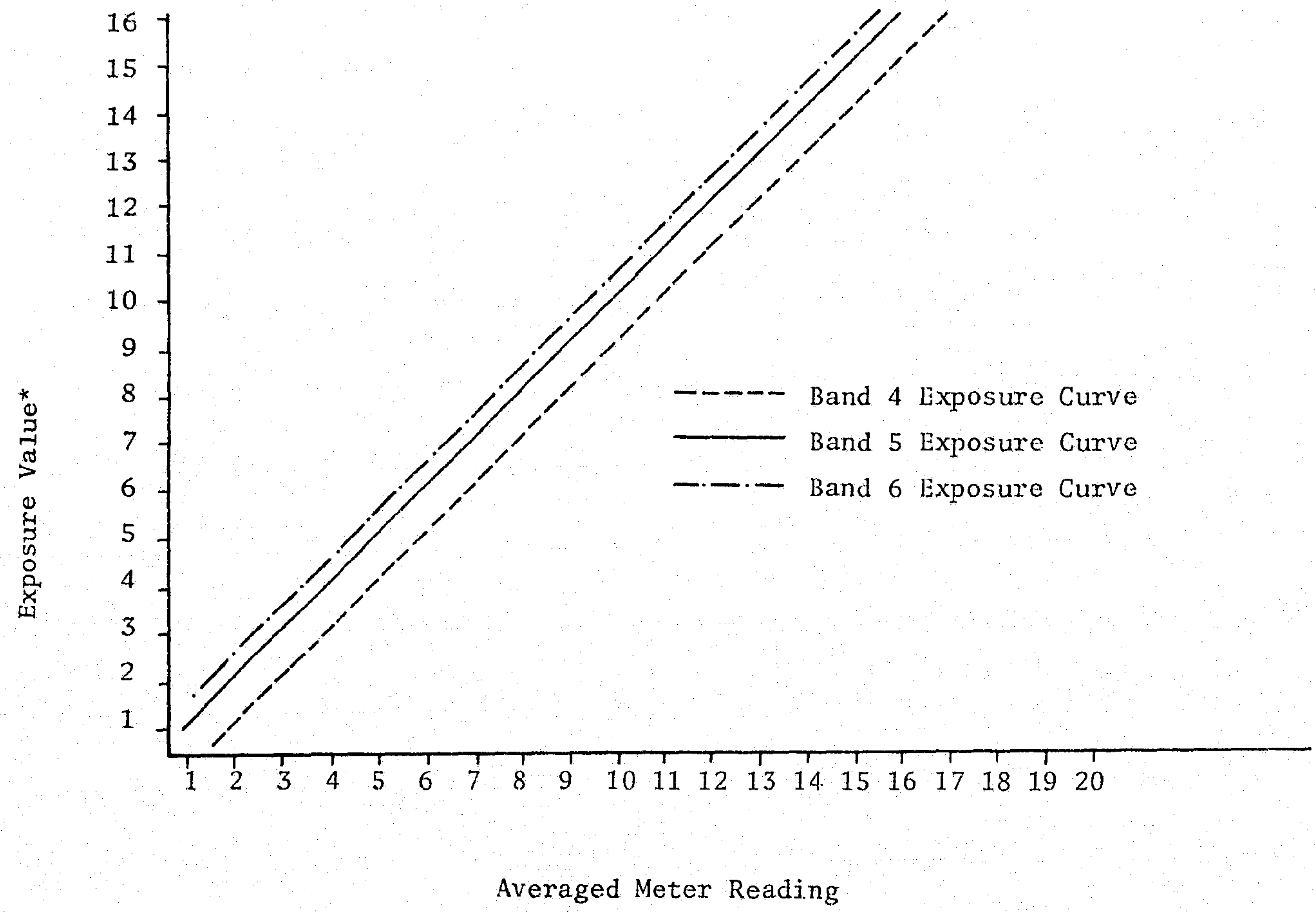


Figure I-8. Example exposure data for the construction of a simulated false-color infrared three band color composite using a conventional light table or a flashbox. LANDSAT MSS Band 4 is combined with a Wratten 47B filter, Band 5 with a Wratten 58 filter, and Band 7 with a Wratten 25 filter. Different exposure curves must be derived for different film speeds and/or different band/filter combinations, as explained in the text.

*Exposure values (EV) are those unique combinations of shutter speed and aperture which yield the same exposure. For instance EV 13 represents the combinations 1/125 second at f/8, 1/60 second at f/11, 1/30 second at f/16, etc.

REFERENCES

Barnes, J. C. and C. J. Bowley, 1974, "Handbook of Techniques for Satellite Snow Mapping", Environmental Research & Technology, Inc., Concord, Massachusetts, 95 pgs.

The author wishes to express a special thanks to Melinda Shackleford for her contribution to this procedural manual.

APPENDIX II

PROCEDURAL MANUAL

REMOTE SENSING AS AN AID IN DETERMINING THE WATER CONTENT OF SNOW

1.0 Introduction

This procedural manual describes the use of Landsat data in combination with conventional ground snow course data to provide an estimate of watershed or subbasin snow water content. The technique is designed to be readily implementable in current operational water runoff forecasting models. Only a small initial capital investment is required and man-time requirements need not be substantial. The technique is designed to complement current snow measurement methods by providing spatial information on snow water content. Consequently it permits more accurate estimates to be made on a basin or subbasin basis. Normally, snow water content estimates are obtained directly from ground-based snow course or snow sensor measurements. The procedure described herein introduces a stratified double sampling approach that relates the ground-based estimates to snow areal extent data gathered from Landsat imagery. The resulting relationships enable low-cost remotely sensed data to statistically characterize the spatial and temporal variability of specific snow depletion environments sampled with ground snow course data. In this manner, satellite data can be used to determine the weight assigned to a particular snow course measurement and also to provide more frequent assessment of snow water content.

For determining snow areal extent, itself, this technique utilizes the Landsat-based procedure described in our Snow Areal Extent Procedural Manual as the remote sensing input. However, non-Landsat remotely sensed data types could potentially provide useful information to characterize the spatial variability, watershed-wide with respect to snow water content. For example, meteorological satellite data could be used with the Snow Areal Extent Procedure to provide more frequent (daily) information, although of lower spatial resolution, basin-wide. The technique can also be refined by the user, if desired, to include machine processing of the satellite data.

2.0 General Approach

The following provides an overview of the remote sensing-aided snow water content estimation procedure.

Sample Design and Measurement

A stratified double sample method is used to develop a basin-wide estimate of snow water content. Under this approach, snow water content information for the whole watershed, as obtained inexpensively on a sample unit basis from Landsat data, is combined with that gained from a much smaller and more expensive sample of ground-based measurements at snow courses (see Figure 13). The result is a basin-wide estimate of snow water content based on Landsat data calibrated by regression on snow course data. Since much of the watershed snow water content variation is accounted for by information gained from the Landsat sample stage, an overall estimate of basin snow water content is possible at more precise levels than available for the same cost from conventional snow course data alone.

The sequential sampling/measurement process proceeds by first locating a sample grid over the watershed. Snow areal extent estimates are quickly made for each sample unit by manual techniques (See Snow Areal Extent Procedural Manual) for the previous snowpack build-up dates and then for the specific forecast date. The snow areal extent data is then combined by a linear equation to generate an index parameter that is correlated with snow water content information that is specific to the forecast date for each sample unit. This linear model is designed to reflect the relationship between snow areal extent and snow depletion behavior, and is specific to the watershed being studied. Some users may choose to develop more complex, physically realistic areal extent-to-water content transformations.

By specifying the precision and level of confidence desired in the basin-wide snow water content estimate and by considering measurement costs in relation to the available budget, one is able to calculate the necessary ground subsample size. Ground snow water content measurements are then allocated to Landsat-based snow water content-index classes (strata) according to weighted random stratified sampling procedures.

Regression relationships are developed between the Landsat snow water content index data and the ground snow water content measurements. These equations are then used to correct all Landsat-based data by ground values of snow water content. The ground corrected values of Landsat-based snow water content information in each stratum or class are added to give a total basin-wide estimate of snow water content, together with an associated precision statement.

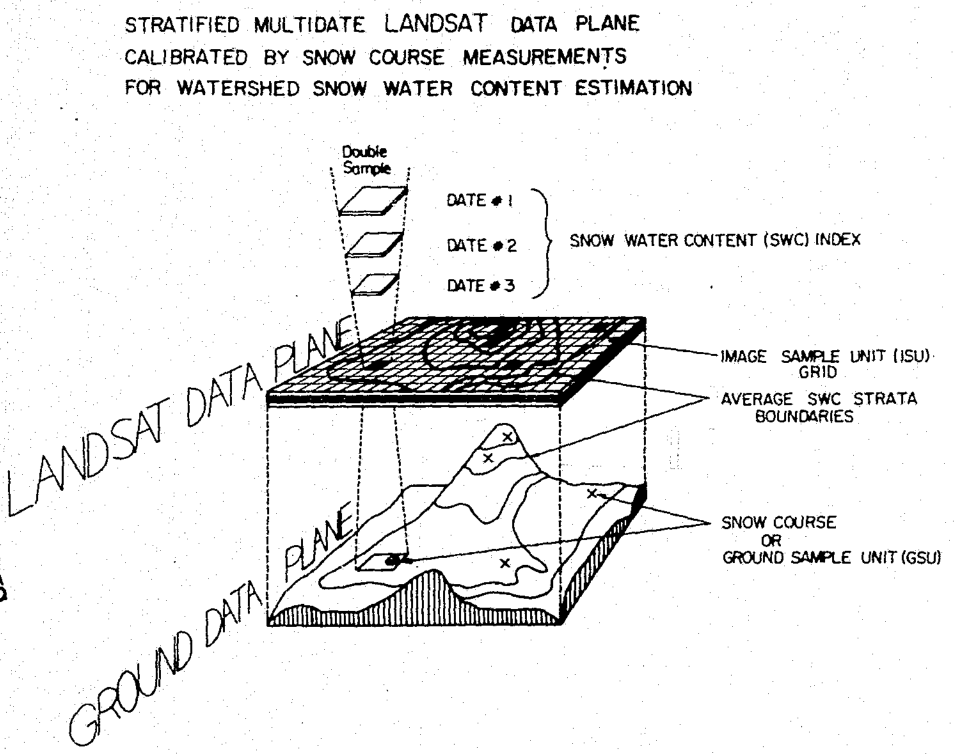


Figure 13. Stratified Multidate Landsat data plane calibrated by snow course measurements for watershed snow water content estimation.

Results and Their Applications

The Landsat-aided snow water content estimation procedure is designed to generate an estimate of total watershed snow water content and an associated statement of precision for a given forecast period. The estimate may then be related by regression equations directly to basin water yield for a given period. Or the statement may be used as another predictor variable in current snow survey or river forecast equations. Grid overlays, when placed either on watershed maps or directly on Landsat imagery, give a location-specific estimated snow water content index for each sample unit. Such information can be used to produce improved hydrologic modelling procedures incorporating this spatial data.

Performance Criteria

Performance criteria for this procedure consist of 1) the precision and accuracy of the estimate of snow water content over the watershed versus the cost of making the estimate, 2) the timeliness of the estimate; and (3) the value of any in-place map products of improved quality that can be produced through use of the procedure.

3.0 MATERIALS AND METHODS

The stepwise procedure for estimating snow water content with the aid of remote sensing is described below:

Step 1: An overall plan should first be developed which will facilitate adoption of the remote sensing-aided snow water content estimation procedure by the user organization. This implementation plan should consider (1) available budget, (2) requirements for either training or obtaining image interpreter(s), (3) type of products desired, e.g. watershed and/or sub-watershed estimates or in-place snow water content maps (4) performance requirements in terms of estimate precision and satellite image acquisition to forecast turnaround time requirements (5) interface of the snow water content procedure with current operational forecasting operations, and (6) startup equipment (stereoscope, photographic laboratory facility) and labor requirements.

Step 2: Color composites should be prepared from Landsat imagery and/or from other satellite imagery types, (e.g. weather service) and the appropriate image sample unit (ISU) grid should be placed over each watershed of interest. In the performance of this step, black-and-white Landsat transparencies should be obtained (e.g. from the EROS Data Center) and transformed into a simulated infrared color composite by a sample photographic procedure described in our "Snow Areal Extent Procedural Manual". In the color-combining process, an ISU grid is

randomly placed over each image so as to cover the watershed of interest. Watershed boundaries should be located on the satellite imagery from 1:250,000 scale U.S. Geological Survey topographic data via use of optical rectification devices (if available) or by manual transfer from map to image. A complete description of the boundary and sample grid overlay is given in the Snow Areal Extent Procedural Manual. Grids on all dates must be in common register. Square image sample units each 400 hectares in size, are recommended. This size is large enough to stabilize variance and small enough to give location-specific snow water content-related information at reasonable cost. The user may choose to modify these image sample unit dimensions as experience is gained with the estimation procedure.

Step 3: The snow areal extent should then be estimated for each Landsat ISU for previous season(s) or current season snow build-up dates. Each ISU should be interpreted, manually, as to its average snow areal extent cover class according to a snow environment-specific technique described in the Snow Areal Extent Procedural Manual. Previous dates of imagery used should include: 1) one of the images covering the average date of maximum snow accumulation in an average snow year; 2) at least one image from an early season snow date in the current snow season; and 3) if possible, another image from a date well into the snow season representing average snow distribution for that date. As will later be discussed in Step 5, these previous snow season images are used to maximize the correlation between the satellite-derived snow water content indices and ground measurements of snow water content for any given sample unit on the forecast date in question.

Step 4. Snow areal extent should be estimated by ISU for Landsat snow season forecasting date of interest, again using the procedure described in the Snow Areal Extent Procedural Manual. Length of the delay that can be tolerated between image acquisition by the satellite and imagery receipt by the user will depend on the use of the snow water content estimate. A very short turn-around time (hours) will be required for weekly or sub-weekly water yield forecasts, but longer times usually will be satisfactory for monthly or seasonal forecasts.

Step 5: Snow areal extent data should next be transformed to snow water content data by Landsat ISU. Snow water content is estimated from the following first order, time-specific model, designed to reflect physical snow depletion behavior in a given melting environment:

$$X_i = \sum_{j=1}^{J} (M_{ij})\ (G_j)\ K_i$$

where X_i = estimated snow water content index for image sample unit i, correlated to corresponding actual ground snow water content data,

M_{ij} = snow cover midclass point based on photo interpretation; expressed on a scale of 0.00 to 1.00 for image sample unit i on the jth Landsat snow season date,

G_i = weight (related to snow depletion zone behavior characteristics) assigned (0.00-1.00) to a past M_{ij} according to the date of the current estimate,

K_i = the number of times out of j that sample unit i has greater than zero percent snow cover, and

J = total number of snow season dates considered.

The basic assumption of this simple model is that the greater the sum of areal snow extent over all dates used and the more often snow is present, the higher will be the expected snow water content. This model is most appropriate in mountainous environments. Each user may want to specify a more sophisticated, and more physically realistic model for his own watershed(s).

Definition of the weighting factor, G_j, will be watershed specific. Generally, weights should approach 1.00 as the dates of imagery approach the date of forecast. The justification of the weighting relationship is that successively more recent climatic events have progressively more importance in determining the actual snow water content on the forecast date in question. To insure reasonably high correlation between X_i and corresponding snow water content values, there usually should be at least three snow season dates considered ($j \geq 3$). Normally, one or two dates of Landsat imagery would be required during the early snow accumulation season. Occasionally, j may be only two, such as when the first date consists of an April 1st snow water map, based on the past year's Landsat data, and the second is the current early snow season date in question. In all cases the sample unit grids on all dates must be in common register with respect to a base date grid location. Starting initial weight suggestions are : 0.25 for the previous year image that is representative of an average maximum snow accumulation date; 0.50 for the early snow season date; 0.75 for dates occurring a month or two before the forecast date; and 1.00 for the forecast date and for all dates occurring within one or two months prior to the forecast date.

Step 6: The ISU's should next be classified and summarized into snow water content strata. Stratification is used to minimize the variance of the final snow water content estimate. Without prior experience on a given watershed, it is best to define two or three strata for first implementation. These strata can be defined by dividing the range of ISU snow water content index values over the watershed into two or three natural groupings (seen by plotting snow

water content index versus number of ISU's). If no natural groupings are present, then the range of ISU snow water content index values should be divided into two or three ranges having approximately equal numbers of ISU's in each stratum.

After each ISU has been coded as to its stratum, the number of ground sample units (GSU's) consisting of snow courses required to satisfy the precision user criterion (allowable error), as established by the user for the snow water content estimate, should be calculated by stratum. (The procedure which our group would consider most suitable for sample size determination on the ground is in the process of development).

Initial implementation of this procedure requires previous information regarding the variability, in each stratum, of the snow water content index, and also a determination of the correlation between ISU and GSU data, the total number of ISU's needed per stratum, and average ISU and GSU costs. This data is most efficiently gained by obtaining Landsat data for a previous snow season that was as similar to average as possible. Steps 1 through 5 should be followed for a mid-season snow date. The stratification portion of Step 6 should then be performed to classify ISU's into strata from which the total number of ISU's per stratum is immediately gained. The variance in Landsat snow water content index by stratum can then be calculated by the standard statistical formula for variance. Next, current ground snow courses and snow sensor locations should be determined relative to the given ISU in which they fall. The overall correlation coefficient between ground snow water content measurements and Landsat-based snow water content index values should then be calculated for the matched ISU's and GSU's. Additional correlation coefficients also should be determined for each stratum if a sufficient number (e.g. $\geq$ 10) of snow courses exist for each stratum.

Image preparation and interpretation costs should also be documented during this initial exercise. Labor, materials, and overhead costs should be documented on an ISU basis as in the example given in Table 1 . Cost per GSU (snow course) measurement can best be developed from the individual user organization's pre-existing data. All cost data for sample allocation should represent operational costs.

Step 7: For the first year of actual implementation, the calculated number of GSU's per snow water content index stratum should be allocated for given ISU's in those strata. This allocation should be based on equal probability selection from the tabular summaries of ISU's generated in Step 6. Consequently, ISU's should be numbered from 1 to N_h in a given stratum and a random number table (or calculator/computer analogue) used to select the calculated number of ISU's to which GSU's will be matched.

TABLE 1. EXAMPLE CALCULATION OF IMAGE SAMPLE UNIT COSTS FOR A LANDSAT-AIDED MANUAL SNOW WATER CONTENT INVENTORY[1]

	Total Cost	Cost per ISU[2]
I. Pre-Inventory		
A. Image Acquisition		
3 LANDSAT dates with 3 bands per date @ $3 per band; the costs of 2 of these dates amortized over 5 dates	$12.60	$.006
Resource Photography		
(Medium Scale Aerial Photography for Image Analyst Environmental Type Training)	$14.29	$.006[3]
B. Image Sample Unit		
Grided LANDSAT Color Composite Print Generation		
Film, Processing, and Printing		
3 dates @ $11 per date		
The costs of 2 of these dates amortized over 5 dates	$15.40	$.007
Labor 0.5 hours per date @$13.50/hr including overhead, 3 dates, the costs of 2 of which are amortized over 5 dates	$ 9.45	$.004

1. Cost data based on 1975 University of California figures.

2. Cost per image sample unit assuming 2218 (780,000 ha test watershed) image sample units in the watershed(s) of interest.

3. Two $500 flights amortized over 5 years, 7 dates per year, and two watersheds.

TABLE 1 (continued)

	Total Cost	Cost per ISU
II. Inventory		
A. Interpreter Training		
1 hr per date, @ $13.50/hr 3 dates, the costs of 2 of which are amortized over 5 dates	$18.90	$.009
B. Image Interpretation		
Ave. 6 hrs per date @ $13.50/hr (2218 Image Sample Units)		
3 dates, the costs of 2 of which are amortized over 5 dates	$113.40	$.051
C. Data Keypunching		
6 hrs per date @ $13.50/hr; 3 dates, the costs of 2 of which are amortized over 5 dates	$113.40	$.051
D. Computer Analysis of Image Analyst Results		
0.075/hr @ $40/hr	$ 3.00	$.001
E. Selection of Random Numbers to Define Ground Sample Units		
0.5/hr @ $13,50/hr amortized over 5 dates @ $13.50/hr	$ 1.35	$.001
TOTAL	$301.79	$.136

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The snow course or sensor should be located in a snow accumulation and depletion environment representative of the average of such environments covered by the given ISU. If it is not efficient to reallocate an already established network of snow courses and sensors, then the snow water content stratum should be identified for each such ground unit by determining the stratum associated with the ISU covering that ground location. After several years of using this remote sensing-aided technique for snow water content estimation, the user may find it desirable from a precision (i.e. variance control) standpoint to reallocate some ground courses to achieve the optimum stratum-by-stratum GSU sample sizes calculated previously. However, before this is done, updated GSU sample sizes should be calculated using stratum-specific ground or image snow water content variance data averaged over successive seasons.

Step 8: Estimates of watershed or sub-watershed snow water content should be calculated, using the equation described in step 5. The values thus obtained should be entered into statistical or physical models to predict water yield. For example, the user could employ the remote sensing-aided snow water content estimate as an input variable in a regression equation for predicting water runoff.

Step 9: Finally, the utility of the above-described procedure for using remote sensing as an aid to estimating snow water content should be evaluated in meeting the water yield forecasting organization's legal or contractual requirements. Utility can be judged by new information gained (e.g. watershed physical relationships), forecasting accuracy or precision improvement, cost savings, or forecast timeliness. Information gained on the precision/cost effectiveness of the procedure and the sensitivity of the water yield forecast models to the resulting snow water content estimates can be used to:

1) refine the model (Step 5) used to calculate the snow water content index,

2) better define snow water content index strata,

3) generate better GSU sample sizes and allocation strategies, and

4) refine the actual snow areal extent interpretation and imagery enhancement and analysis procedures used in Steps 2, 3 and 4.

APPENDIX III

Procedural Manual Outline

REMOTE SENSING AS AN AID IN WATERSHED-WIDE
ESTIMATION OF WATER LOSS TO THE ATMOSPHERE

I. INTRODUCTION

A. Need for the data on evapotranspiration (ET) for water yield forecast models.
B. Importance of evapotranspiration in agriculture, silviculture, reservoir operation, etc.
C. Impact of remote sensing techniques in aquisition of required data for evapotranspiration estimation

II. OBJECTIVE

A. Objective of this procedural manual
B. Definition of terminologies used for maximum potential, potential, and actual evapotranspiration

III. MATERIALS AND METHODS

A. General approach
B. Multistage statistical sampling design
C. Three information levels
D. Required input data and data source
E. Physical modeling of evapotranspiration
F. Stepwise Procedure for Integrating the Above

IV. EXPECTED RESULTS

A. Areal distribution of input parameters to ET models
B. Watershed-wide distribution of evapotranspiration based on level I models

V. IMPLICATION OF RESULTS

A. Application of ET results in RFC hydrologic model
B. Evaluation of RFC model output after using ET models results as a direct input
C. Direct comparison of the ET models results with available conventional data on evapotranspiration

VI. CONCLUSIONS

A. General conclusions
B. Importance of remote sensing

VII. CASE STUDY

A. Application of the methodology developed in this investigation to the Middle Fork of the Feather River Watershed, Northern California

APPENDIX IV

Procedural Manual Outline

REMOTE SENSING AS AN AID IN WATERSHED
-WIDE ESTIMATION OF SOLAR RADIATION

I. INTRODUCTION

A. Need for the data on solar radiation components for evapotranspiration and hydrologic models
B. Impact of remote sensing in acquiring solar radiation data

II. OBJECTIVE

A. Objective of this procedural manual
B. Definitions of terminologies used for several solar radiation components

III. MATERIALS AND METHODS

A. General approach
B. Required input data and data source
C. Physical modeling of shortwave and longwave radiation

IV. EXPECTED RESULTS

A. Areal distribution of watershed parameters, i.e., boundary, elevation, slope, aspect, etc.
B. Watershed-wide distribution of net shortwave, net longwave, and net solar radiation
C. Implementation of net solar radiation data in hydrologic models
D. Stepwise Procedure for integrating the above.

V. CONCLUSIONS

A. General conclusions
B. Importance of remote sensing

VI. CASE STUDY

A. Application of the procedure developed in this investigation to the Middle Fork of the Feather River Watershed, Northern California

APPENDIX V

Project Outline

REMOTE SENSING AS AN AID IN THE INVENTORY AND MANAGEMENT OF THE MULTIPLE RESOURCE COMPLEX FOR A GIVEN WILDLAND AREA

I. INTRODUCTION

A. Usefulness of information on multiple resource complex inventory for planning and management of a forested area

B. Role of remote sensing in acquisition of information with respect to various types of resources in an area

II. OBJECTIVES

A. General Objective of the project

B. Specific Objective defined with cooperation of U.S. Forest Service at Plumas National Forest and Plumas County Planning Department

III. METHODOLOGY

A. Definition of the resources (e.g., soils, vegetation, etc.) to be inventoried

B. Development of a statistical sample design and measurement specification for collecting the desired information

C. Identification of available data sources

D. Collection of required satellite, aircraft, and ground-truth data

E. Analysis of the acquired data and documentation of the analysis procedure for various types of resources

IV. RESULTS AND CONCLUSIONS

A. Preparation of results

B. Evaluation of the results

C. General concluding remarks and evaluation of remote sensing techniques in providing required data for such an inventory

V. CASE STUDY

A. Application of the procedure developed in this investigation to an area selected jointly by U.S. Forest Service at Plumas National Forest, Plumas County Planning Department, and Remote Sensing Research Program

VI. PREPARATION OF PROCEDURAL MANUAL

Chapter 4

PROCEDURAL MANUAL FOR DEVELOPING A GEOBASE INFORMATION SYSTEM--

(An Outgrowth of Remote Sensing-Related Water Demand Studies in Central California)

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Chapter 4

PROCEDURAL MANUAL FOR DEVELOPING A GEOBASE INFORMATION SYSTEM

INTRODUCTION

During the past several years personnel of the Geography Remote Sensing Unit (GRSU) on the Santa Barbara Campus of the University of California have concentrated their work under this NASA grant on the performance of remote sensing-related water demand studies in the predominantly agricultural lands of Central California. In the course of this work it has become increasingly apparent that greatly improved efficiency could result if a geobase information system could be developed that would permit remotely sensed data to be used in conjunction with conventional resource inventory data in inventorying an area's "total resource complex". A first draft of the Procedural Manual that might be used in developing such a system is presented in this chapter.

It is to be emphasized that such a Procedural Manual is complementary to, rather than duplicative of, the one currently being developed by personnel of the Remote Sensing Research Program on the Berkeley Campus. It is true that the manual being developed by that group also seeks to provide a stepwise procedure for using remote sensing-derived information in the inventory of an area's "total resource complex". However, the area being dealt with by that group is an almost entirely wildland area in California's Sierra Nevada Mountains where timber and forage production are primary resource management objectives. Furthermore, the ancillary data per-

taining to that area's natural resources is likely to be of a significantly different nature than the ancillary data pertaining to California's Ventura County--the coastal area in which efforts of our GRSU are being concentrated.

Before proceeding further with the subject matter of the present chapter we wish to invite attention to Special Study No. 1 of Chapter 7 in the present Progress Report. That study serves to summarize some of the considerations, as viewed by our GRSU personnel, that are involved in the development of a decision-oriented resource information system that incorporates remotely sensed data. Hence it provides some highly pertinent background information with respect to the Procedural Manual that appears in this chapter.

Within this chapter we will detail those procedural steps necessary to produce merged, registered Landsat-derived land cover and digital terrain data sets, as information sources toward the inventorying of the "total resource complex." The steps that follow here involve the image processing of Landsat/MSS (multispectral scanner) and DMA (Defense Mapping Agency) digital terrain tapes. This processing requires considerable computer software to manipulate the data sets into compatible, geobased formats. Because of these processing requirements, it is recommended that only agencies that are planning to develop fairly sophisticated image processing capabilities attempt to follow these procedures. Such considerations exemplify the crucial decision that resource management agencies must face in determining whether or not to develop a geobase information system, with remote sensing capabilites.

Information requirements of resource management agencies at the international, national, state, regional and local levels continue to expand. To effectively inventory the total resource complex, resource managers are faced with the need to store, update, and access environmental data in an accurate and efficient manner. The approach taken by this research effort, as an attempt to offer solutions to these resource management needs, is:

1. Conduct a survey of information requirements of county level resource managers using Ventura County, California as the prime example.
2. Derive a land cover classification of the two topographic quad study areas from geometrically rectified Landsat/MSS data.
3. Merge the classified study area data set, with terrain data (elevation,slope, and aspect) from a Defense Mapping (DMA) digital terrain tape, in the context of an image-based information system.
4. Determine habit zones of various flora and fauna by interrogating the merged land cover and terrain data sets in conjunction with pre-determined biological habitat charactersitics, i.e. vegetation/elevation/aspect.

The general approach as outlined above will seek to implement a digital information storage system that utilizes remote sensing inputs for resource managers at the county level. Each of the above tasks are described in greater detail in the following pages.

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IMPORTANT BASIC CONSIDERATIONS

The Need for a Survey of County Level Resource Management Information Needs.

The operational downfall of many geographic information systems in the past has been the result of a failure to meet the needs of the intended user. All too often packaged systems have been purchased and implemented, with little consideration of what the user agency requires. Ideally an information system should be custom designed to meet user requirements. But even if an interested agency purchases a marketed system, the designers must consider the characteristic elements of a user's information needs such as resolution, timeliness and formats.

The initial step in our approach has been to request from the Ventura County Public Works Agency their highest priority information requirements. From the list of requirements an assessment was made as to which categorical needs could be met by merging remote sensing data with another data type in the framework of a demonstration project. The highest priority requirements as determined by those agency members with which most communications were made were involved with determining land cover and terrain. A secondary interest of crop identification in the Oxnard Plain agricultural region was also stated, and chosen to be a secondary focus of the research effort.

The Ventura County Board of Supervisors are currently applying for financial aid from the California State Office of Planning and Research (OPR) to conduct an in-depth survey of the information requirements of all county agencies involved in resource management activities. The survey will be conducted,with a careful minimization of biasness,by members of the Ventura County Public Works Agency and student interns from UCSB. The survey will seek to determine categorical, spatial and temporal

resolution, and output data format information requirements for each division within all resource-related agencies. GRSU researchers will then determine the optimal data source (including remote sensing) as well as how the data is to be incorporated into the information system. Ventura County personnel will make the final decision on priorities for implementation of each data type.

Factors Involved in Deriving a Land Cover Classification from Landsat/MSS Data

As the two high priority information requirements involved the determination of surface cover types at a fairly coarse spatial resolution level, it was decided upon to use Landsat multispectral data to derive this information. The study areas chosen to make the analysis are the areas represented by two 7.5 minute topographic quad sheets. The flora and fauna habitat study area is represented by the Matilija Quadrangle and a predominantly agricultural area by the Oxnard Quadrangle. Land cover classification and other data sets will be merged on a quad-by-quad basis. The Ventura County agencies are planning to develop DORIS so that the 7.5 minute quad is the working storage base.

A digital approach is being utilized and will thus be the scope of analysis in this section and in the Procedural Manual that follows. Consideration of manual remote sensing derived classification will not be discussed here. Readers are referred to references that discuss the manual vs. digital approaches to Landsat derived classification.

The geometric correction of the raw Landsat data is best accomplished prior to classification so that the scene is as close to orthometric as possible. This becomes necessary when developing a geographic-based

information system, as data values must represent their true geographic location. Rectification has been achieved through a two-dimensional least squares fit technique, as part of the DIRS image processing software package. This method requires the selection of accurate ground control points from the Landsat scene (Goddard Space Flight Center, 1976).

Statistical techniques in the digital machine processing of Landsat/MSS data for land cover classification have been the focus of a great deal of research in the past ten years (Anuta and MacDonald, 1971; Su, 1972; Steiner, 1972). The general progression of processing steps is as follows (Lintz and Simonett, 1976):

a. Determination of class categories

b. Feature extraction

c. Pixel classificaiton

d. Output of classification results

Statistical approaches to the classification vary from supervised to non-supervised and parameter to non-parameter. Supervised classification involves the selection of training fields for each class, where the feature extraction phase simply derives class statistics (mean, standard deviation, covariance matrices) as a model for subsequent classificaiton. Non-supervised classification involves the grouping of pixels into classes according to the similarity of their multiband reflectance characteristics. Classification is then based on the statistical feature extraction of the "clustered" groups. Parametric and non-parametric approached differ on the assumption of a gausian distribution of spectral values, and thus go about a different means of deriving classification statistics.

A supervised, parametric approach is being used to classify land cover in the Ventura Study areas. This method was decided upon after considering the time and costs associated with the varying approaches, and the availability of in-house processing software and literature pertinent to the subject. The software used to derive the classification is LARSYS, created at the Laboratory of Applications for Remote Sensing (LARS) at Purdue University. The actual classification algorithm uses a maximum-likelihood rule.

Th classification of the Matilija Quad study area for flora and fauna habit assessments is based primarily on natural vegetation cover classes. These classes are of a level significant to the general vegetative class scheme associated with the habitat zones. They are:

- Coastal sage scrub
- Chaparral
- Oak Woodland
- Grass Lands
- Non-Vegetative (Barren and Urban)
- Fresh Water
- Agriculture (crop types for the Oxnard study area)

Factors Involved in Merging the Land Cover and Terrain Data Sets

To explore the synergistic charactersitics of merged data sets in an image-based information system context, the Landsat derived land cover data is being registered with the terrain data of the DMA digital terrain tape. This merged geocoded data set should provide the information necessary to determine the flora and fauna habitat zones required by Ventura County resource managers.

Registration is achieved by finding ground control or tie points, relating Landsat pixels and terrain grid cells that represent the same geographic location. This is achieved digitally through a computer algorithm, after the selection of tie points. Upon registration, the stacked data sets become four levels of a digital image-based information system. These levels are:

1. Land cover
2. Elevation
3. Slope
4. Aspect

Levels 3 and 4 are calculated by simple software routines from the raw elevation values of the terrain tape. This is discussed further in the Procedural Manual that follows. By referencing the digital values to a geographic coordinate system, the data sets become geocoded.

Considerations in Determining Habitat Zones by Interrogating Registered Data Sets

The interrogation of registered, image-based data sets by extracting data for pertinent locations, requires fairly sophisticated information system's software. To utilize this data, one must be able to access any point (grid cell), line (chain of grid cells) or polygon area (grid area within a connected chain of grid cells). An image-based system is based on the raster grid as the smallest data storage cell. Thus, if data is needed for a polygon delineated area, a polygon-to-grid transformation is necessary.

The determination of potential habitat zones will be derived from certain land cover and terrain information criteria. This is based on natural history research conducted by Ventura County flora and fauna experts.

STEP-WISE PROCEDURE

NOTE:

The purpose of the procedures discussed in Special Study No. 1.* is to establish the information requirements of the county level resource manager and to design an information system utilizing remotely sensed data that will most efficiently meet most of these information requirements. An analysis of the improved efficiency of a geobase information system utilizing remotely sensed data over conventional resource inventory data handling is a difficult task. By analyzing the derivation of a few of the major information categories in the context of a geobase information system, we can begin to realize the efficiency implications of the system. This section will detail those procedural steps necessary to produce merged, registered Landsat-derived land cover and digital terrain data sets, as information sources toward the inventorying of the "total resource complex." The steps that follow here involve the image processing of Landsat/MSS (multispectral scanner) and DMA (Defense Mapping Agency) digital terrain tapes. This processing requires considerable computer software to manipulate the data sets into compatible, geobased formats. Because of these processing requirements, it is recommended that only agencies that are planning to develop fairly sophisticated image processing capabilities attempt to follow these procedures. Such considerations exemplify the crucial decision that resource management agencies must face in determining whether or not to develop a geobase information system, with remote sensing capabilities.

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* See Special Study No. 1 in Chapter 7 of this report

Step 1. Acquisition of Landsat Computer Compatible Tapes (CCT): The initial step is to acquire the multispectral data contained within a Landsat/MSS computer compatible tape. A CCT may be purchased from the EROS Data Center (EDC) in Sioux Falls, South Dakota for $200. The selection of the appropriate date of image data is critical and should be made only after reviewing the search list of available data products published by EDC. This list contains such information as the date of imagery available, amount of cloud cover, and image cover coordinates for any requested frame.

A particular date of imagery must be considered for both the season of year in which it was imaged and the characteristics of the data as influenced by both the sensor system and the environment. Particular seasons of the year yield more significant land cover classifications th n others due to a greater separability of signatures for varying cover types. If there have been no prior studies into the selection of the optimum season for classifying a particular region, a survey of the literature may yield such information from research of an area of similar environmental characteristics. Percentage of cloud cover is an obvious consideration, with little or no cloud cover desirable. Because no cloud cover is allowable for the area to be classified it is important that an image film product be studied before acquiring a CCT. Image cover coordinates show whether or not the area of interest is wholely contained within the Landsat scene (which makes the image processing and subsequent classification considerable easier).

Step 2. Acquisition of Digital Terrain Tapes:

To acquire a Defense Mapping Agency Topography Center (DMATC) digital terrain tape one needs only to make an order to the National Cartographic Information Center in Reston, Virginia. The digital data computer tape version of an Army Mapping Service (AMS) 1:250,000 scale topographic quadrangle map can be purchased for about $27. The accuracy of the original AMS topographic model has often varied from quad to quad, with the digital terrain tape for that model acquiring these inacurracies. Information concerning the accuracy of individual tapes may be obtained by contacting the Office of Research and Technical Standards, 519 National Center, Reston, Virginia, 22092 (telephone: 703-860-6291). If a particular tapes inaccuracy or inherent resolution grid is too gross to meet the needs of the users, they may consider the acquisition of other terrain data products (e.g. USGS digital elevation model DEM).

Step 3. Access Study Area and Observe Data Quality:

Because both Landsat and digital terrain data tapes include data coverage of areas much larger than the 7.5 minute quadrangle study area, the data pertinent to the study area must be extracted for the total scenes contained on the tape data. For the Landsat tape, a selected subimage of the entire scene that is somewhat larger than the study area is initially pulled off to improve subsequent classification processes and reduce the costs of processing unnecessary data. The terrain data of the study area is immediately extractable from the digital terrain tapes by physically measuring the appropriate X-Y coordinates, and inputting this information into an accession software routine (Dozier, 1977).

The alteration of the grid size may be necessary to successfully register the differing data sets. This is done by resampling the values at different spacing intervals, usually within the accession routine. Observation of the data quality is achieved by printing line-printer maps of the raw data and obtaining film product images to examine for trends of extraneous data. This is particularly important for the Landsat data to check for striping and other radiometric "gliches" that sometimes occur in the data acquisition phase. If indeed some of the data is determined to be extraneous, a different date of image data may be needed. It is important that data quality for the entire area of interest be consistent and of the highest order of geometric and radiometric accuracy if it is to be input into an information system.

Step #4 - Reformat Data Sets:

In order to manipulate and later merge the raw data sets, it is required that the physical format of the recorded data values be altered. This is due to the fact that no standard format exists for the recording and development procedures of the data.

Reformatting of the raw Landsat data's physical format is necessary so that it may be manipulated by most image rectification software. This is true for both the Digital Image Rectification System (DIRS), which is the software being utilized in this particular research task, and the Video Image Communication and Retrieval (VICAR) software packages.

The data must be again altered into a format compatible with the classification software. This may not be necessary in the case of "in-house" software development to achieve the same classification of multi-spectral data.

Another format change is required from the necessity to have both Landsat derived land cover and digital terrain data sets in like-reading formats. The data format for the digital terrain tape which runs from bottom to top, column by column, should be reformatted to match the left to right, row by row format of the landcover classification data.

Step #5 - Rectify Landsat Data:

The geometric correction of the raw Landsat data will be necessary, so that the scene is as close to orthometric as possible. Rectification may be achieved through a two-dimensional least squares fit technique, such as is part of the DIRS image processing software package. This method requires the selection of accurate ground control points (GCP's) from the Landsat scene, (Goddard Space Flight Center, 1976). An accurate, controlled transformation of the image data is achieved by creating a mapping function that relates the image GCP's to a geographical map coordinate. A transformation achieved by adjusting the data according to the satellite altitude and earth rotation information is not acceptable. This step will become obsolete if and when the EROS Data Center begins to implement the Master Data Processor, which will allow one to purchase Landsat CCT's that are already geometrically corrected.

Most image processing software involved with geometric corrections offers the capability of altering the pixel size and shape through a re-sampling algorithm. Such a capability is necessary here if we are to register the rectangular 79 x 57 meter pixel grid of Landsat with the 63.5 meter grid of the digital terrain tape. Within the rectification processing, the Landsat grid should be re-sampled and made square at

a pixel cell size compatible with user needs and output devices.

Step # 6: Classify Landsat Scene

The land cover classification of the Landsat spectral data itself, with the wide variety of approaches that have been used, could be the subject of many procedural manuals. As has been noted in the previous section, a fairly classical supervised approach has been utilized for this particular study, and will be expanded upon here. The reader is advised to consult the following references that deal with approaches to Landsat derived land cover classifications (Lintz and Simonett, 1976).

The initial machine processing of the Landsat CCT entails running a clustering algorithm in an attempt to separate spectrally similar classes. Through such an algorithm, one is able to get a handle on the number of spectral classes that are significantly separable. An output map of pixels, as they are assigned to a cluster class, is a useful tool in the selection of training field sites. The next step is a careful location and identification of training fields representing each desired class, as influenced by the degree of clustering and a familiarity with within scene cover types. An overlay or zoom transfer projection of a United States Geological Survey 7.5 or 15 minute topographic map (topo-sheet), a photo, or other ancillary map data (e.g. land use/land cover map), can be used to identify Landsat pixels of known class-types. Field checks of training site locations are recommended, preferably by a quick aerial survey. Note: it is important that training sites for a given class represent the diversity of conditions of that class within the scene to be classified.

The pixel boundaries of training sites for each class are then input into a class statistics algorithm to compute means, standard deviations and convenience materials.

A divergence or separability measure should follows for 2 reasons:

1. To examine which band combination provides optimum separability between spectral classes.
2. To determine which classes are hopelessly unseparable.

An aggregation of classes that cannot be separated at a given significant level may be desirable. With the derived class statistical model, each pixel data value is assigned to a spectral class (representing a given land cover class), according to the classification rules of the particular algorithm utilized (e.g. maximum likelihood).

Classification results are then output both as performance table statistics and as classification maps. Classification tables give statistics of test field accuracies, roughly indicating the degree of classification accuracy. A line printer or film-writer output of the classification map can be used to systematically check the accuracy of the classification (re-training, combining classes, creating new classes). The final classified map is stored on magnetic tape or disk.

Step #7: Calculate Terrain Information:

In addition to elevation values from the raw digital terrain tapes, other terrain information such as slope and aspect can be derived. This information can be calculated by simple software processing. In essence the software will compute a gradient vector at each point, with the vector magnitude as the slope angle data and vector direction as the aspect

(Krebs, et al., 1976). Further computation may change the calculated slope and aspect values to classes of arbritary boundaries.

Step #8: Register the Data Sets

Depending on the requirements of the user, data set registration may or may not be necessary. If the only requirement is to extract a table listing land cover types per elevation or slope or aspect for a given area, then it is only necessary to interrogate the individual geocoded data sets. If the data sets are to be merged to produce a map of combined land cover/terrain derived classes or land cover classes utilizing terrain and spectral channels alike, then accurate registration is necessary. This is accomplished through the selection of tie points identifible on all data sets to be merged. For our concerns these tie points are the ground control points used in the rectification process. These are input into a registration algorithm.

Step #9: Extract Pertinent Data

Even with properly rectified and registered data sets, the combined data is not useful until it can be accessed and displayed. To do so, software must be utilized to extract data values at a desired point, line, or polygon area. The user must specify either the digital coordinates of the desired data location (from a coordinate digitizer) or geographical coordinates where data is stored in a geographical-based information system.

SUMMARY AND RECOMMENDATIONS

A major step toward assuring improved management of existing land resources is the development of computer capabilities to systemize, standardize, store, retrieve, compare, analyze, and model geographic data in formats acceptable to a broad array of users. The merging of remote sensing and computers is now sufficiently advanced to make a geo-image-based system economical and powerful enough to be useful. Development of geobased information systems will be facilitated by the changes in formats mentioned previously, as well as the recent advances in computer devices, which allow for low cost storage of data (memory) and low cost processing (inexpensive dedicated systems).

Specifically, Ventura County is interested in obtaining tabular outputs of terrain information (elevation, slope, and aspect), per land cover classification, for a given polygonal area that is to be assessed. The development of hardware and software combinations and procedures to meet this typical user agency's predefined information requirements is a principal objective of this project. In a similar fashion we are dedicated to the interactive education of Ventura County and GRSU personnel in all phases of our proposed investigation. This is being done for 2 basic reasons: 1) to insure that the resource inventory methodology developed is germane to user needs; and 2) to insure that the specific user has the expertise to operate the system on a stand alone basis once GRSU's work has been completed.

PROPOSED FUTURE WORK UNDER THE GRANT

In the coming months we will continue to stress the development, expansion, illustration, and editing of the procedural manual for the accomplishment of a total resource inventory in a predominantly agricultural environment. We feel that during the current reporting period we have made a good start and have essentially established a framework upon which we can build a useable document. A major goal also in the coming months will be the production of high quality illustrative material to document the step-wise procedure laid out in the manual. In this effort we are fortunate to have the close cooperation of personnel from Ventura County to insure that our product (procedural manual)is designed in such a fashion as to be readily useable by user agency personnel.

PERSPECTIVE ON POTENTIAL FOLLOW-ON RESEARCH

Current efforts have demonstrated that the development of a geobased information system is possible in Ventura County. These efforts have been reviewed by county, state and federal personnel, and it has been concluded that a comprehensive survey of the resource data needs and the development of such a system would be of benefit to the County agencies involved, as well as state and federal resource managers (see Appendix 3).

To pursue the use of this technology at local levels (beyond the depth found here in this examination of the role of remote sensing in the conduct of a total resource inventory in a predominantly

agricultural environment) requires the cooperation of many agencies, as well as sufficient funding and expertise to implement a project which will lead to the establishment of a viable resource information system.

A cooperative base between several agencies has been established, as part of this project, and sufficient expertise exists within the present staffs of County agencies to create such an information system.

A program which will produce for the County a "state of the art" system required to meet the mandates previously discussed, which will meet current and anticipated needs in the most efficient and economical manner, will be proposed as a major project for follow-on work under other NASA funding after the termination of the current grant and requires that the following courses be pursued.

Federal and State data needs have led to the funding of enlightened efforts to solve resource management problems. Funding of the current project ends in May, 1978. In order to take advantage of state of the art research, it will be necessary to fund additional user need surveys, data acquisition, system development, and personnel training.

As Ventura County already has the start of a comprehensive data base and an automated mapping system capable of sophisticated output products, as well as personnel capable of implementing a Decision Oriented Resource Information System, it is felt that funding may be developed to a large extent through grant monies provided by agencies

such as National Aeronautics and Space Administration, U.S. Geological Survey, National Science Foundation, Department of the Interior, Housing and Urban Development, etc.

Preliminary work has been completed on a proposal to fund additional data input and to support the establishment of an information system which will supply decision makers with up-to-date information as an aid in policy decisions, and also provide County staff with a powerful tool to help in project implementation.

A proposal to the United States Geological Survey has been written by VCFCD and GRSU to digitize certain baseline (roads, watersheds, municipal boundaries, etc.) mapped data. It is anticipated that this data will be merged with the Landsat tapes currently being prepared at UCSB and the supporting digitized data (flood zones, flood plain, zone of influence, etc.) being prepared at VCFCD.

The state of California is currently engaged in establishing a State Environmental Data Center. Since many areas of mutual interest will be explored by both groups, it is recommended that cooperation and communication be formally set up between that center and this County, with the goals of cost savings and efficient use of the data and equipment.

Due to the recognition of a multiplicity of potential applications, a proposal to the California Office of Planning and Research is being prepared by VCFCD in cooperation with the Ventura County

Environmental Resource Agency, to fund a survey of data needs within the County structure. Within this proposal will be an inventory of current data resources and recommendations pertaining to desired format. The high degree of similarity in user needs could result in substantial savings to each participating party.

Total funding is being requested, but if less than total funding is supplied, then the County's share of such a study will be supplied by monies from the general fund.

In view of the acceleration of technology in the fields of remote sensing, environmental modeling and computer science, it can be reasonably expected that new data and techniques will become available.

In an effort to maintain a "state of the art" information system, County personnel have recommended that a permanent committee to investigate future advances in the science and technology fields be appointed. This committee would be broad-based among County agencies and supported by sufficient expertise to properly evaluate such advances as to their applicability to County data needs.

Preliminary negotiations between UCSB and Ventura County regarding both limited workshops and more extensive training of County personnel in the use of these new sources of data and the transfer of supporting technologies are currently under way.

It is anticipated that funds for this effort will follow a pattern similar to the other efforts involving this project, but the educational aspect does allow for funding through a variety of established sources.

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APPENDIX 1

INTRA-COUNTY SUPPORT

a) Review of project by Ventura County Environmental Resource Agency.

b) Approval by Board of Supervisors to pursue further project funding.

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County of Ventura

ENVIRONMENTAL RESOURCE AGENCY

MEMORANDUM

To: Mr. Lin Koester, Director

Date: Dec. 2, 1977

From: Robert Laughlin, Project Evaluation Section

Reference No.:

Subject: REVIEW OF PUBLIC WORKS AGENCY PROPOSED REMOTE SENSING PROGRAM (D.O.R.I.S.)

EVALUATION

The proposed Remote Sensing Program has been reviewed by the major Divisions within this Agency including APCD, Environmental Health, Agricultural Commissioner, Plan Development and Plan Administration. It is the unanimous judgment of these Divisions that this proposed program would provide a useful information and planning tool for both the County and this Agency, and, therefore, it should receive our support.

POTENTIAL APPLICATION AREAS

Each Division has its own unique program area where this information system could be applied. These areas are briefly described for each applicable program area by Division.

Agricultural Commissioner

Program Areas: Crop census and disease detection.

Applicability: The current technology in the NASA sensing system allows the collection of information in units of approximately 1.1 acres in size. According to Les Haworth, this base unit is too large to allow application now, however, as technology is refined to permit a smaller unit of data collection, this system can be applied to the above program areas. NASA has planned satellite flights within a few years that will reduce the size of the data unit to less than ¼ acre.

Air Pollution Control District

Program Areas: None

Applicability: The APCD has indicated this program would not provide any advantages over their existing data collection system. However, information on air quality and emissions which is currently collected by the APCD could be fed into the DORIS system for use by other Divisions and Agencies in their program areas. Therefore, while the APCD would not be a user, per se, of this system, they could help expand its usefulness.

AOF 89A

Plan Development and Plan Administration Divisions

Program Areas:

1. Project Review.
2. Environmental Analysis.
3. Development of General Plans.

Applicability:

Environmental Inventory (i.e., maps, data listings, summaries), etc.). Examples:

1. Existing land use.
2. Vacant land (Countywide or within specified sub-areas).
3. Prime agricultural land.
4. Zoning.
5. Pending and probable future projects.
6. Special districts (e.g., sewer and water service areas).
7. Political boundaries.
8. Mineral resources.
9. Flood plains.
10. Slopes.
11. Watersheds and sub-watersheds.
12. Soil groups.
13. Transportation facilities.
14. Historic and archaeologic sites.
15. Vegetation groups.
16. Natural features.
17. Acquifer recharge areas.

Plan and Project Review

1. Initial studies (i.e., issue/problem identification for further study).
2. Impact assessments.
3. Alternative site identification.
4. Cumulative impact analysis (i.e., impacts of pending projects).
5. Searching and calculating distances to or from a specific location or phenomenon.
6. Surrounding land use and zoning.

Planning and Analysis Studies

1. Environmental holding capacity of an area (e.g., McHarg model).
2. Potential build-out of an area based on existing zoning.
3. Agricultural encroachment models.
4. Land use trends.
5. Land capability analysis.
   a. Industrial location model.
   b. Identification of areas suitable for intensive residential development, recreational facilities, etc.
   c. Identification of areas suitable for intensive agricultural use or special crops.
   d. Identification of areas suitable for open space preservation.

Environmental Health Division

Program Areas:

1. Review of private on-site sewage disposal systems for soil suitability.

2. Monitoring public health concerns regarding changes in surface water quality and solid waste disposal.

Applicability:

The D.O.R.I.S. system could incorporate existing data on soil suitability and high groundwater areas. This information could be used for initial studies and review of proposed on-site sewage disposal systems. D.O.R.I.S. could also be used to monitor indiscriminate dumpings of solid waste or creation of abandoned landfill areas.

cc: Victor Husbands
Jan Bush
Bill Anderman
Les Haworth
Dennis Davis

BOARD OF SUPERVISORS
COUNTY OF VENTURA

Seal of Ventura County
Seal of the Board of Supervisors

MONTY C. LISH, County Executive

ROBERT L. HAMM, County Clerk and
Clerk of the Board of Supervisors

TED GRANDSEN, District 4
CHAIRMAN
(Camarillo Heights, Las Posas, Somis, Moorpark, and Simi Valley)

DAVID D. EATON, District 1
(East Ventura, Montalvo, Saticoy, El Rio, North Oxnard, and Nyeland Acres)

ABSENT -- EDWIN A. JONES, District 2
(Camarillo, Thousand Oaks, Newbury Park, Conejo Valley, Oak Park, and South Coast)

J. K. (KEN) MAC DONALD, District 3
(Ojai, Meiners Oaks, Oak View, Fillmore, Piru, Santa Paula, and West Ventura)

THOMAS E. LAUBACHER, District 5
(Oxnard and Port Hueneme)

LEGAL NOTICES

The Public Facilities Corporation will hold a Special Meeting Wednesd December 14, 1977 at 12:00 o'clock noon, in the Private Dining Room or the Pierpont Inn, San Jon Road, Ventura. Their Regular Meeting for Wednesday, December 21, 1977 is cancelled.

The Board of Supervisors will sit as the Board of Equalization for hearings, Thursday, December 15, 1977 beginning at 8:30 a. m.

1. Invocation - Reverend Larry Baker, First Southern Baptist Church.

2. Pledge of Allegiance to the Flag of the United States.

3. Minutes for the County and Special Districts governed by the Board held on Tuesday, December 6, 1977. Direct publication of Summary of Proceedings by Clerk of the Board in the Santa Paula Chronicle.
APPROVED

PUBLIC WORKS AGENCY

Award of Contracts for:

4. Camarillo Airport Building No. 256 Renovation (CP 78-10).
APPROVED

5. Animal Holding Facility - Eastern County (CP 78-9).
APPROVED

6. Contract with BTC Laboratories for Inspection Services - Camarillo Airport - Building Renovation Bldg. No. 256 (CP 78-10) and Work Furlough Center Rehabilitation (CP 78-8). Direct Auditor to Encumber Funds.
APPROVED

7. Contract with the National Oceanic and Atmospheric Administration (NOAA) for Participation in Southern California Releveling Program (SCRP).
APPROVED

8. Amendment No. 1 to Agreement for Engineering Planning Services with the Ventura Regional County Sanitation District re Seawater Intrusion and Water Quality Sampling.
APPROVED

9. Agreement with the City of Oxnard for Services in Sweeping County Streets.
APPROVED

10. Cooperative Agreement with the City of Thousand Oaks for City to Render Road Maintenance Services to the County in Unincorporated Areas Adjacent to the City. APPROVED

PUBLIC WORKS AGENCY CONTINUED

11. Final Map for Tract No. 2412-4, Santa Rosa Valley. (ALSO SEE FLOOD CONTROL DISTRICT ITEM)
APPROVED

12. Request for Authorization to Purchase a Truck Mounted Generator, Road Department.
APPROVED

13. Draft of Letter to be sent to Federal Legislators Representing Ventura County Expressing Concerns Relative to Minority Business Enterprise Requirement of the Local Public Works Act of 1977.
APPROVED

14. Acceptance of Subdivision Street Improvements - Tract No. 2453-2.
APPROVED

Waterworks Districts

15. Waterworks District No. 1 - Acceptance of Water Improvements in Tract No. 2406-1. (ALSO MOORPARK COUNTY SANITATION DISTRICT ITEM)
APPROVED

16. Waterworks District No. 8 - Waterworks District No. 17 - Bell Canyon Sewage Pump Station - Request for Appropriation Transfer.
APPROVED

Moorpark County Sanitation District

17. Acceptance of Sewer Improvements in Tract No. 2406-1. (SEE WATERWORKS DISTRICTS ITEM 15)
APPROVED

Flood Control District

18. Joint Letter with Environmental Resource Agency Requesting Authorization to Apply for a State Office of Planning & Research Grant to Identify and Develop Applications of Data Made Available Through Satellite Imagery (LANDSAT).
APPROVED

19. Contract with Toups Corporation for Inspection Services - Silver Strand Storm Drain Project (FC 78-7). Direct Auditor to Encumber Funds.
APPROVED

20. Environmental Negative Declaration - Arroyo Conejo - Unit II.
APPROVED

21. Final Map for Tract No. 2412-4 - Acceptance of Storm Drainage Easements and Flowage EAsements. (SEE PUBLIC WORKS ITEM 11)
APPROVED

HEALTH CARE AGENCY

22. Assignment of Hospital Claims to Accounts Adjustment Bureau for Collection. REQUIRES 4/5THS VOTE
APPROVED BY 4/5THS VOTE

23. Physician Contracts.
APPROVED

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APPENDIX 2

COUNTY PROJECT ORGANIZATION

POLICY CONTROL TEAM

The policy control team will be comprised of the County Public Works Agency and the County Environmental Resource Agency. These two agencies will be responsible for assisting the Board of Supervisors in defining policies relevant to the project and insuring compliance with these policies.

The Public Works Agency, as team leader, is responsible for maintaining fiscal control of project funds.

PROJECT DIRECTOR

The Staff Conservationist, Flood Control Division of Public Works will be responsible for organizational and fiscal management. The Staff Conservationist will ensure that the work completed by the DORIS program development team is consistent with the policy direction of the policy control team and the Board of Supervisors.

DORIS PROJECT DEVELOPMENT TEAM

This team will be responsible for the technical development of DORIS and as such is the heart of the project. A Staff Conservationist position in the Public Works Agency will be responsible for this team and will be assisted by the Systems Analyst for computer technology support and an Assistant Staff Conservationist for cartography and remote sensing technology support. The Program Development Team

will coordinate with the remaining five teams by receiving user need information and providing technical support in the areas of computer technology and remote sensing. This team will be responsible to the Project Director for fiscal and organizational management as well as direction concerning the Board of Supervisors' policy.

The Project Development Team will receive assistance from UCSB staff in the form of software development assistance, training in the areas of cartography and remote sensing and hardware support.

ENGINEERING APPLICATIONS TEAM

The responsibilities of the Engineering Applications Team are to evaluate and process project requests which entail engineering applications. The initial evaluation consists of determining the feasibility of using "Decision Oriented Resource Information System" application based on system involvement versus output product and the present "state of the art" capabilities in performing engineering analysis and design.

Processing of the project involves:

1. Classifying the type of application and identification of the project's objectives.

2. Selection of the input parameters required to develop and analyze the project.

3. Coordination with the Project Development Team in interpreting and integrating the input parameters and the engineering applications and analysis required to produce the specific objectives.

4. Review and verification of the output integrity.

The Engineering Application Team is also responsible for coordinating and assisting the Technical Support Team and the Program Development Team in the development of computer programs for engineering applications and the review of "packaged" engineering computer program from other sources to assure applicability to regional user needs.

This team will also monitor user needs and identify engineering application shortcomings in the "state of the art" of the system.

The Engineering Applications Team will consist of a full-time Senior Engineer in the Public Works Agency and a staff of "on-call" selected experts in various engineering disciplines including a hydrologits, geologist, hydraulic engineer, traffic engineer, and maintenance engineer.

The Senior Engineer, as team leader, will be responsible for coordination with the involved engineering disciplines and the Program Development Team. Responsibilities will include implementation of the project through DORIS applications, monitoring user needs in computer software and hardware technical training. The Senior Engineer will also be responsible to the Project Director for fiscal management and policy direction.

The successful development and application of this system depends on cooperative multilevel agency interaction.

CAPITAL PROJECT APPLICATION TEAM

I. CLASSIFY CAPITAL PROJECT APPLICATIONS

- A. Geological Applications
- B. Hydrological Applications
- C. Water Management
  1. Flood Control
  2. Reclamation/Conservation
  3. Water Demand
  4. Water Quality
- D. Shoreline Management
- E. Agricultural Applications
- F. Urban Applications
  1. Comprehensive Planning
  2. Impact Assessments
- G. Environmental Assessments

II. IDENTIFY CAPITAL PROJECT OBJECTIVES

- A. Monitoring Change
- B. Inventory
- C. Simulation
- D. Impact Determination
- E. Location Optimization
- F. Cost Analysis
- G. Displays

III. INTEGRATE INPUT PARAMETERS

- A. Interpret and Extract Data Sets
  1. Remotely Sensed Images
     - a. Automated Interpretation
     - b. Manual Interpretation
  2. Prepare Exogeneous Data
     - a. Maps
     - b. Field Survey
     - c. Statistics
- B. Transcribe Data to Base Maps
  1. Polygon Format
  2. Grid Format
- C. Integrate Data Base Maps
  1. Provide Locational Congruence
  2. Provide Classification Reconciliation
- D. Encoding
  1. Transferral of Base Maps Data onto Computer Compatible Media

5. Searching and calculating distances to or from a specific location or phenomenon

6. Surrounding land use and zoning

C. Planning and Analysis Studies

1. Environmental holding capacity of an area (e.g., McHarg model)

2. Potential build-out of an area based on existing zoning

3. Agricultural encroachment models

4. Land use trends

5. Land capability analysis

   a. Industrial location model
   b. Identification of areas suitable for intensive residential development, recreational facilities, etc.
   c. Identification of areas suitable for intensive agricultural use of special crops
   d. Identification of areas suitable for open space preservation.

APPENDIX 3

LETTERS OF SUPPORT

State of California
GOVERNOR'S OFFICE
OFFICE OF PLANNING AND RESEARCH
1400 TENTH STREET
SACRAMENTO 95814

DMUND G. BROWN JR.
GOVERNOR

(916/322-3784)

1 December 1977

Robert Foulk, Project Director
Decision Oriented Resource
Information System (D.O.R.I.S.)
County of Ventura
597 East Main Street
Ventura, California 93009

Dear Bob:

I've only just had a chance to review the proposal you circulated in draft form at the NCSL conference, and I wanted to let you know how excited I am by the prospect of what you hope to establish in Ventura County. Although I worry that you may be expecting too much of the Environmental Data Center we are setting up and would be delighted if we could meet even half of the functions you outlined for our program in your proposal by the end of the first year, my emphasis throughout the project will be upon establishing a range of services that can benefit city and county governments directly.

Considering how much you have accomplished already, I have high hopes that Ventura County and your program will provide us with the opportunity to establish a model of how state and local governments can cooperate in this field. You are already so far ahead of us that I am really looking forward to running to catch up in the months ahead.

Sincerely,

William L. Kahrl

William L. Kahrl
Director of Research

WLK:vhw

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STATE OF CALIFORNIA — RESOURCES AGENCY

EDMUND G. BROWN JR., Govern

DEPARTMENT OF CONSERVATION

DIVISION OF MINES AND GEOLOGY

SION OF OIL AND GAS

SACRAMENTO, CA 95814
1416 Ninth Street

December 5, 1977

(916) 445-8733

Mr. Robert Foulk
Public Works Agency
Flood Control Department
County of Ventura
597 East Main
Ventura, CA 93001

Dear Mr. Foulk:

Thank you for the information on your proposed cooperative project with the USGS and University of California at Santa Barbara to help develop a geographical based information system for the county. The integration of such a project with the capability of your automated mapping system, we believe, has the potential for producing a land data system with outstanding performance characteristics.

As you know, we currently are testing digital processing of map information and are seriously considering eventually developing a land data system in cooperation with other agencies, to handle data of statewide value. Assuming this eventuality, we would both benefit from the rapid and relatively inexpensive exchange of data your system would permit.

Good luck with your project.

Sincerely,

O C Leaf

O. C. Leaf
Land Resource Protection Unit

American Public Works Association
CAMRAS
City of Memphis
125 NORTH MAIN • MEMPHIS, TENNESSEE 38103 • (901) 528-2722

DR. WM. L. BATHKE
Project Director

December 9, 1977

Mr. Robert Foulk, Project Director
DORIS Program
Flood Control Department
Public Works Agency
597 East Main
Ventura, California 93001

Dear Mr. Foulk:

Thank you very much for the opportunity to meet with you and to discuss the DORIS program.

Since our meeting I have reviewed the draft document which you offered to me describing the general aspects of the regional information system. It is very clear that your visions of the end product system should permit 1) a cost savings to the county agencies involved and 2) an opportunity to utilize data that is more up-to-date and relevent to the decision making process.

I am particularly interested in your efforts because of the parallelism with the APWA CAMRAS program (abstract enclosed). The APWA program does not incorporate the features of remotely sensed data and yet there is definitely a requirement for easy manipulation of such data in a regional system. It would appear that perhaps the end products of both the DORIS and APWA programs might very well have a technical interface that would ultimately strengthen and complement each other.

As Project Director of CAMRAS I am very much interested in your projected plans for getting DORIS off the ground and will assist you in any manner available. It is important that your effort be recognized as a viable course to follow -- not necessarily easy but one that should benefit all of the participants and program supporters. If you or others in your program effort would be interested I have some general APWA-CAMRAS material that describes more of the program and the anticipated regional benefits. You are welcome to it.

Mr. Robert Foulk, Project Director
DORIS Program
Public Works Agency
December 9, 1977
Page Two

Good luck and please keep me posted. If you have any suggestions as to how we might further work together I would appreciate your comments.

Very truly yours,

APWA-CAMRAS

W L Bathke

Dr. William L. Bathke
Project Director

WLB:CE

Enclosures

cc. John A. Lambie

CHAPTER 5

TECHNIQUES FOR LAND USE MAPPING FROM REMOTELY SENSED IMAGERY DEVELOPED FROM WATER DEMAND STUDIES IN SOUTHERN CALIFORNIA

Co-Investigator: Leonard W. Bowden

Contributors: Claude W. Johnson,
David A. Nichols.

DEPARTMENT OF EARTH SCIENCES

RIVERSIDE CAMPUS

UNIVERSITY OF CALIFORNIA

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TECHNIQUES FOR LAND USE MAPPING FROM REMOTELY SENSED IMAGERY DEVELOPED FROM WATER DEMAND STUDIES IN SOUTHERN CALIFORNIA

Co-Investigator: Leonard W. Bowden, Riverside Campus

Contributors: Claude W. Johnson, David A. Nichols

5.1 INTRODUCTION

Efforts by the Riverside Campus group have been directed toward user-oriented documentation of systems and procedures developed under this grant during the past several years. This documentation is intended for resource management personnel and as an aid in educating resource management students in remote sensing and related techniques.

Two separate but related procedures are currently being documented. First, the procedural manual for land use mapping is undergoing revision in response to critiques of the draft manual. Secondly, another procedural manual is being prepared which specifically addresses the computerization aspects of land use as well as other spatial types of data. This latter manual has been used in draft form as a classroom lab manual but is not yet ready to be distributed for critical review to the general public. It is of note, however, that the California Department of Water Resources has obtained the draft documentation and is currently implementing some of the programs on their computer.

This semi-annual report includes a summary of procedural manual evaluations and production cost determination. The report also provides an overview of the automated procedures of the Spatial Information Processing System (SIPS). The complete revision of the procedural manual will be published in the annual report in May. Complete documentation of SIPS is anticipated for the same date.

5.2 PROCEDURAL MANUAL - TECHNIQUES FOR MAPPING LAND USE FROM REMOTELY SENSED IMAGERY

Efforts on the procedural manual have been directed toward improving the manual based upon evaluations received from outside reviewers. A complete draft (reported in the semi-annual report dated December 31, 1976) was submitted to the grant technical monitor and the land use analysts of the Department of Water Resources, Los Angeles Division, for comment (a brief outline of the procedure is listed for reference). One recommendation was to provide some indication of production costs. This has recently been done for a sample map and is reported below.

5.2.1 Outline of Land Use Mapping Procedural Manual

The procedural manual for Techniques of Land Use Mapping is divided into three basic sections or phases of operation: 1) Planning hase; 2) Mapping Phase; and 3) Data Compilation and Presentation Phase. The following is an outline of the 13 steps involved in the mapping procedures:

PLANNING PHASE

Step 1 Define Goals and Objectives
- a. Establish the purpose of the Land Use Map
- b. Establish the Temporal Base

Step 2 Establish a Classification System

Step 3 Establish Accuracy of Parameters

Step 4 Select Data Source(s)

Step 5 Select the Scale and Type of Source Imagery

Step 6 Establish a Base Map

MAPPING PHASE

Step 7 Method of Scale Change, Rectification, and Data Transfer

Step 8 Conduct a Random Field Check of the Completed Work Map

DATA COMPILATION AND PRESENTATION PHASE

Step 9 Select a Method of Final Reproduction

Step 10 Prepare a Clean Copy of the Land Use Map

Step 11 Convert "Clean" Work Map to Machine Format
- a. Machine Digitizing
- b. Procedural Error Editing
- c. Geometric Editing

Step 12 Produce Statistical Tabulation of Land Use Data

Step 13 Produce Final Land Use Map(s)

5.2.2 Evaluation of the Procedural Manual

The general response to the manual by the two different reviewers was that it does not contain enough specific details. In defense of the manual we must point out that our original instructions were to limit the manual to no more than twenty pages. To provide the detail recommended it would require double, perhaps triple that space. One possible, but not optional solution to this problem is to orient the procedural manual as a guideline for the establishment of a land use mapping system and then make liberal use of references to remote sensing manuals (e.g. Manual of Remote Sensing--published by the American Society of Photogrammetry). Another solution is to treat the subject matter in as many pages as necessary while guarding against jargon and verbosity.

The other most frequent criticism of the draft was that many of the statements were vague and should contain additional examples to provide clarification. An attempt will be made to correct any vagueness and each step of the procedure will be documented with at least one, if not two or three, figures. The figures will illustrate the procedure or contain examples which illustrate the procedure.

5.2.3 Production Costs of Representative Computer Map

One of the factors not included in the draft of the procedural manual was production costs. To provide data to determine production costs a representative sample map was produced with each step being carefully monitored to determine the time required in both days and hours. The sample region selected was the U. S. G. S. 7½ minute quad sheet containing the area around Redlands, California. The region contains an equal mix of urban and rural areas representing a map production problem of average difficulty. Consequently, regions containing a greater percentage of urban area would have higher production costs and regions with a greater percentage of rural area would have lower production costs. The following table provides the production hours and actual calendar days required for each production step.

Production Step	Actual Hours	Sessions	Days
Image Interpretation	15	8	4
Field Survey Check	8	2	2
Preparation of Clean Copy	18	8	4
Digitizing (Data Conversion)	31	9	5
Procedural Error Edit	8	4	2
Data Preparation for Computer (Job control prep., etc.)	4	-	-
Geometric Error Editing	30	5	5
	114	36	23

The above list is for labor costs only. Other production costs (i.e. computer time, plotter time, etc.) will be established and included in the

final report.

It is noted that the number of calendar days required exceeds the actual hours of labor by roughly twice as many days (8hours). The type of work involved is tedious and it has been determined that 2 hours is the average length of time for an individual to work on any one of the production steps before the number of procedural errors exceeds acceptable limits. The alternative of course is to have more than one individual participate in the various steps, thus reducing the production schedule for an average map to 15 total calendar days.

The image interpretation was performed by an individual with high expertise and an intimate knowledge of the region. Lesser trained individuals will require more interpretation time. The digitizing and editing procedures were accomplished by an individual with limited experience. Hence, trained personnel would be expected to complete the task with fewer errors and less editing time.

The final report will include a detailed analysis of the costs per number of units mapped, type of map produced, cost per size, as well as other pertinent data.

5.3 OVERVIEW OF SPATIAL INFORMATION PROCESSING SYSTEM

5.3.1 Introduction

The Spatial Information Processing System (SIPS) consists of a suite of related computer programs which can be used to perform selected resource information processing and graphic output tasks. These programs have evolved and are still evolving in response to specific data processing and informational requirements on a project-by-project basis. Most projects for which SIPS has been adapted and implemented rely on remote sensing as a primary data input. The basic goal of SIPS, therefore, has been to utilize information system technology for processing and enhancing remotely sensed data in resource evaluation programs.

A major design philosophy of SIPS has been the creation of a map compilation and geographic base file handling facility, flexible enough to facilitate the use of the software as specific applications are defined. An attempt has been made to provide for a variety of data input, processing options, and information outputs. It is felt that the key to flexibility is the careful design of data structures and the ability to convert from one data structure to another.

It would be presumptuous for the designer of any geographical information system to assert that all or even a majority of spatial processing functions have been provided. In fact, spatial data processing is an ambiguous concept which is only operationally defined by the activities of practitioners, often in response to rather narrowly defined application criteria. A rigorous definition of spatial data processing tasks and the creation of a spatial data processing language is a goal that is yet to be achieved.

SIPS provides the user with many useful data processing capabilities and the flexibility to expand as required. Present capabilities include: 1) map data encoding; 2) geographic data base creation; 3) graphic output in the form of computer generated maps; 4) area calculation and aggregation; and 5) data structure conversion. Each of these capabilities is described below:

Map Data Encoding

A common map or aerial image can be conceived of as a storage device for the geographical data that is present on its surface. The arrangement, selection and graphical qualities of that data convey spatial information. Electronically readable data storage media, such as punched cards, magnetic tape, etc., can be used to store geographical data as well as printed media. In order to electronically store a map there must be some means by which the informational components of the map can be identified. This involves identifying the shape, location and juxtaposition of the geometric entities along with the attributes of those entities--referred to here as map encoding.

There are two fundamental approaches to map encoding; both of which rely on a cartesian coordinate system. The first approach is to consider the map as consisting of a finite set of small, regularly shaped and regularly

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distributed areas (termed grid cells, resolution elements, pixels, etc.). Attributes are then assigned to each cell. Points are approximated as single cells, lines are approximated as linearly contiguous cells, and irregular areas are approximated as arearly contiguous cells. One distinct advantage to this system of encoding is that the regular geometry allows positional information to be implicit in the data stream. Therefore, no explicit coordinate information need be stored. The Landsat data collection system as well as many other digital scanner systems encode spatial information in this cellular manner. In the case of remote sensor encoding systems, the attribute of each resolution element is a function of the spectral reflectance in a specific wavelength of a cell on the ground.

The second approach to map encoding is to consider the map to be an infinite but spatially bounded set of points (the points become finitely limited given the resolution of a recording device). Geographic entities are then represented by points or connected sets of points which define either a line or a boundary condition. Attributes are assigned to points or point groups by association. Since there is no regular predictable geometry, explicit coordinates must be stored and maintained. The advantage of this system is that highly accurate positional information for most data configurations is available at little penalty in data storage resources. This encoding system also requires that the map geometry exist on a printed graphics medium before data capture can take place.

Both systems of map encoding have advantages and disadvantages with regard to analysis and mapping. SIPS supports both types of data structures and allows the conversion from one type to another so that the proper encoding scheme (data structure) may be used where it is most appropriate in the data flow.

Geographic Data Base Creation

The simple encoding of map data is normally not sufficient for certain further processing functions to take place. First, the process of map encoding is highly likely to result in errors which may give rise to incorrect map representation or cause data inconsistencies for further processing. Secondly, additional information may need to be generated and merged to produce a data structure useful for graphical and analytic operations. A phase of 'map compilation' is required which involves data editing and processing of the original encoded input data. The output from the map compilation phase is a geographic data base represented by a data structure which is suitable for many applications. SIPS provides for geographic data base creation given either of the two basic encoding systems and alternative geographic data structures.

Automated Mapping

Maps made with the aid of a computer have been in existence for approximately 20 years. Automated cartography developed along with advances in computer hardware and software. Once the problems associated with encoding and storing a map were resolved it became apparent that the computer could assist in more than just making maps from spatial data. In fact, the computer could be asked

questions about the map it stored. Thus the data organization inherent in automated cartography logically led to the development of geographic information systems. The additional requirement of analytic functions, however, led to the inclusion of additional data in the formal structure.

The power of complex data structures for geographic information systems must lead to a point of view that the ability to draft maps with the aid of a computer is a by-product of the overall processing effort. That is not to say that care and thought should not be given to the mapping process, rather that mapping software should rely on data inputs which are sufficiently general for the larger overall efforts of geographic information system implementation. Reciprocally, any geographic information system should take advantage of the encoding and data structuring effort to produce maps, where appropriate, with the aid of a graphics output device. Maps are an important means of communicating the informational inputs and outputs of a spatial data processing system to the user. SIPS supports automated mapping on either the commonly available line printer or the generally available x-y plotter. Mapping by the line plotter for map editing and choroplethic displays is provided. Output on the line printer is accomplished with programs which are proprietary. Line printer mapping programs are, however, generally available at very low acquisition and installation cost.

Area Calculation and Aggregation

Two of the questions most often asked of a geographic information system are 'where?' and 'how much?'. The question of 'where' is dealt with via the coordinate system and map outputs. The question of 'how much' implies areal extent and is answered via the coordinate definition of spatial extents from which the areas of geographic attributes are measured. SIPS allows the user to calculate the area of polygons at various stages of processing. One program, written specifically for area information generation, allows the aggregation of area by attributes associated with each polygon. That is, for each distinct attribute code the total area in the map having that attribute is determined.

Data Structure Conversion

The design of geographic data structures is intimately intertwined with hardware configurations, software architecture, and output requirements. Considerable effort has been oriented toward designing data structures which have the highest information content-to-storage requirements ratio while satisfying hardware and software performance criteria and analytic requirements. Much of this effort, however, has not been rigorous but is based on the best judgments of the system designers. The philosophy behind SIPS is to allow several different data structures to be used where most appropriate, and to develop algorithms which allow the conversion from one data structure to another. It is felt this approach lends a considerable amount of flexibility in terms of the kinds of data which can be processed.

5.3.2 System Organization

This section describes the software organization and hardware environment in which SIPS has been developed and implemented. Essentially SIPS consists of a library of stand-alone programs which perform specific functions in a batch processing environment.

5.3.2.1 Software Organization

There are two basic approaches to geographic information system software organization. One approach utilizes the concept of a subroutine library from which the user selects the appropriate modules to perform a specific task. Another approach, employed by SIPS, is to create program packages, with specific functional tasks and a wide variety of options, which exist in a program library as stand-alone executable units. The former approach requires the user to select the appropriate modules for the desired procedure and to assure proper subroutine linkages. The user is therefore required, in the absence of a high level control language, to have considerable programming and system control experience. The latter approach, while incurring slightly more storage overhead, allows a user to operate the software with no programming experience. Figure 5.1 is a flow chart which depicts the software organization, data formats, and data flow through SIPS.

SIPS software provides the resource planner with several options of input and output. Input may take the form of; 1) thematic maps such as soils, vegetation, etc.; 2) spatially associated tabular data, such as census data; and 3) remotely sensed data, either in a classified line and sample format or as areas delineated from conventional aerial photography. Outputs possible with SIPS are: 1) geographic base files in either cartesian or universal (e.g. UTM, state plane) coordinates; 2) annotated maps; 3) choroplethic shaded maps; 4) area summaries; and 5) frequency histograms.

A short description of each element of the flow chart (Figure 5.1) is given below.

Tabular and Map Source Data

This input includes prepared thematic maps and spatially associated tabular data. It is assumed for polygon data that mapping units are closed polygons which do not overlap and have an associated attribute or set of attributes. For raster data it is assumed that the data have been coded in a matrix form or are derived from existing raster data banks (e.g. DMA digital terrain data).

Analogue Remotely Sensed Data

This data input form includes all data gathered by remotely sensed means and used in an analogue (photographic) format.

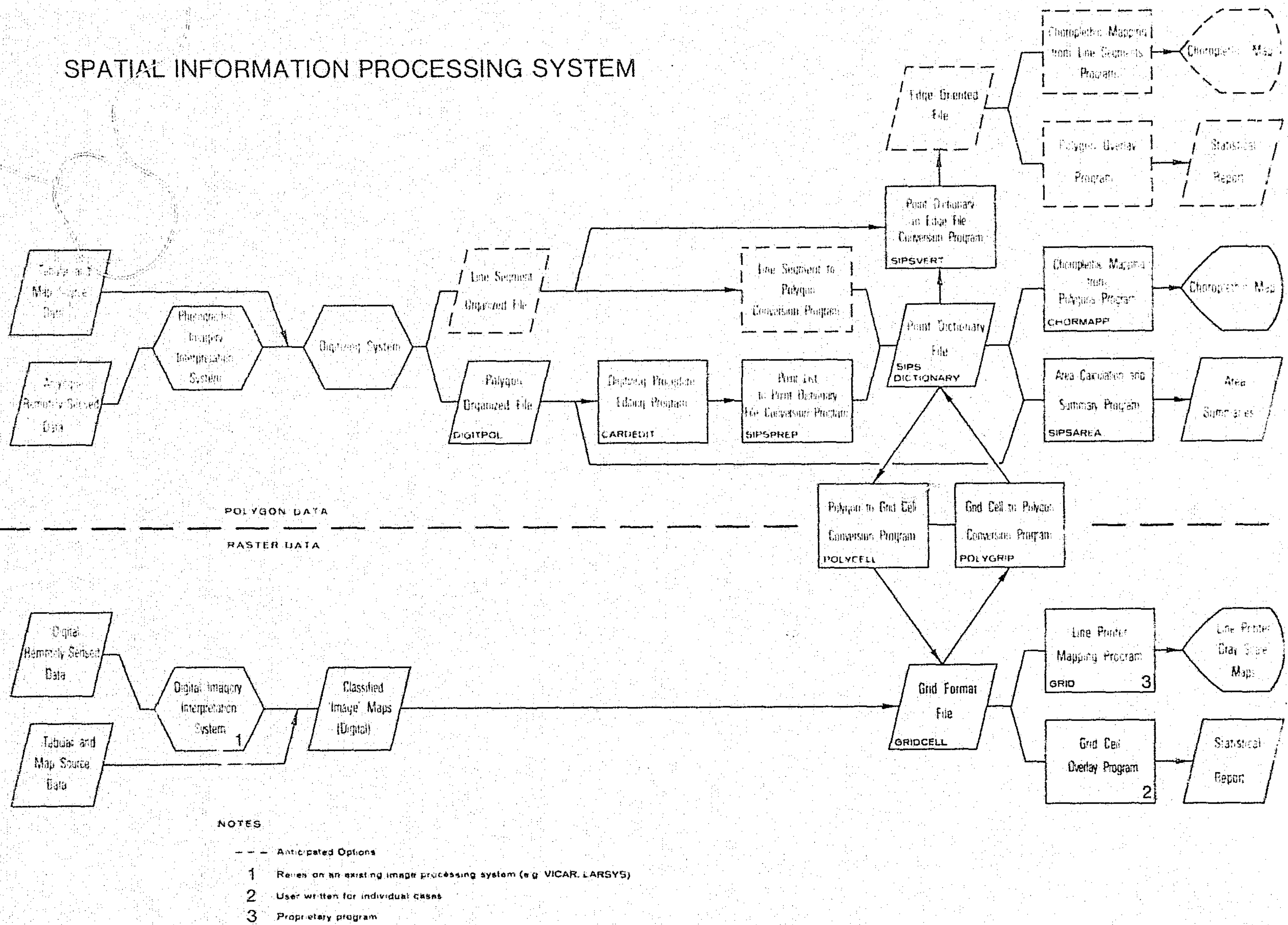
SPATIAL INFORMATION PROCESSING SYSTEM
Digitizing System
Line Segment Organized File
Polygon Organized File
DIGITPOL
Digitizing Procedure Editing Program
CARDEDIT
Line Segment to Polygon Conversion Program
Point List to Point Dictionary File Conversion Program
SIPSPREP
Point Dictionary to Edge File Conversion Program
SIPSVERT
Edge Oriented File
Point Dictionary File
SIPS DICTIONARY
Polygon Overlay Program
Statistical Report
Choropleth Mapping from Polygons Program
CHORMAPP
Area Calculation and Summary Program
SIPSAREA
Area Summaries
POLYGON DATA
RASTER DATA
Polygon to Grid Cell Conversion Program
POLYCELL
Grid Cell to Polygon Conversion Program
POLYGRIP
Digital Remotely Sensed Data
Digital Imagery Interpretation System
1
Classified 'Image' Maps (Digital)
Tabular and Map Source Data
Grid Format File
GRIDCELL
Line Printer Mapping Program
GRID
3
Line Printer Gray Scale Maps
Grid Cell Overlay Program
2
Statistical Report
NOTES
- - - Anticipated Options
1 Relies on an existing image processing system (e.g. VICAR, LARSYS)
2 User written for individual cases
3 Proprietary program

Figure 5.1

Digital Remotely Sensed Data

Remotely sensed data in a digital format, such as that available on Landsat Computer Compatible Tapes, may be input.

Photographic Interpretation System

Remotely sensed photographic format data which are not digital must be interpreted according to a specified procedure. See Chapter 5, NASA grant NGL 05-003-404, Semi-Annual Report, December 1976.

Digital Interpretation System

Remotely sensed digital format data which have not been output to film and used in analogue format must be processed and interpreted using a resource oriented image processing system. The image processing system is not a part of SIPS.

Classified Image Map

Input to SIPS from the digital interpretation system should be in the form of a classified image map on magnetic media. The value for each resolution element represents an information class. It is preferable that this image be generalized by the use of a nominal filter.

Digitizing System

Digitizing involves the machine-aided encoding of polygon boundaries by identifying the x, y coordinates of the boundary lines.

Polygon Organized File

Digitizer output may be organized according to the point list data structure. That is, each polygon is encoded in sequence with all perimeter coordinates in sequence. Presently, SIPS supports this digitizing procedure only.

Line Segment Organized File

Digitizer output may be organized according to individual line segments with pointers to the left and right side polygons for which the line segment defines a boundary. This type of digitizing is not presently available but is anticipated.

Digitizing Procedure Editing Program

The CARDEDIT program is used to detect procedural and formatting errors in the digitizer output records.

Line Segment-to-Polygon Conversion

When line segment digitizing becomes available a utility program will be developed which will perform a conversion from a line segment to a polygon data structure.

Point List-to-Point Dictionary File Conversion

The SIPSPREP program converts from a point list to a point dictionary file.*

Polygon-to-Grid Cell Conversion Program

The POLYCELL program converts from a polygon data structure to a grid cell format.

Edge Oriented File

Although the final topologically oriented data structure has not been finalized it will employ the concept of the winged edge which gives branching information about line segments and is useful for polygon search and cycling as well as many other analytical purposes.

Point Dictionary-to-Edge File Conversion Program

The SIPSVERT program performs the conversion from a polygon oriented data structure to an edge oriented topological data structure. SIPSVERT has been written but has not been finalized pending the ultimate design of the winged edge data structure.

Point Dictionary File

The SIPS Dictionary file is the primary polygon data structure used by SIPS. It is based on a sequential list of pointers to polygon coordinate values for each polygon.*

Grid Cell File

The standard SIPS format for input and output of grid cell structured data is the GRIDCELL file. It basically consists of a record for each line of data with the value in the record as the z coordinate and the position within the record as the sample coordinate.

Grid Cell-to-Polygon Conversion Program

The POLYGRIP program converts from a gridcell file to a SIPS Dictionary file.

*For an explanation of this data structure terminology, see Peucker and Chrisman, "Cartographic Data Structures", The American Cartographer, Vol. 2, No. 1, April 1975.

Choroplethic Mapping From Line Segments Program

This anticipated program will produce choroplethic maps* from a winged edge file. This will allow for dropping boundary lines between polygons which have the same mapping classification.

Polygon Overlay Program

The polygon overlay program, when written, will allow the boolean combination of two polygon data sets.

Choroplethic Mapping From Polygons Program

The CHORMAPP program produces area aggregation by pre-set classification levels, histogram output, and choroplethic maps in either shaded or annotated form.

Area Calculation and Summary Program

The SIPSAREA program produces a listing of total area for each unique polygon attribute in several selectable reporting units.

Line Printer Mapping Program

The GRID program is used to display grid cell formatted data on the line printer. This program is not a part of the SIPS system because it is proprietary.

Grid Cell Overlay Program

The grid cell overlay program is a user written program for combining two or more grid cell structured data sets. These programs are easily written with a minimal amount of programming expertise.

5.3.2.2 Hardware Configuration

This section describes the computer hardware systems around which SIPS has been developed. There are three distinct processing systems used by SIPS; 1) the general purpose processing system; 2) the digitizing system (cartographic data input); and 3) the plotting system (cartographic data output). The general purpose processing system is the campus computing facility at U. C. Riverside. The other two systems are operated and maintained by the Department of Earth Sciences at U. C. Riverside.

General Purpose Processing System

This computing system consists of an IBM 360-50, supporting batch processing only, with the following specifications:

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*The term "choroplethic" pertains to the systematic description and analysis of regions.

- MVT-OS operating system
- 8 series 2314 disk drives
- 3, 800 BPI, 9 track tape drives; 1, 556 BPI, 7 track tape drive
- 1 megabyte of memory
- other standard peripheral devices

Digitizing System

The digitizing system is schematically represented in Figure 5.2. Output is normally to the keypunch as on-line editing capability via the NOVA 1200 is presently limited.

Plotting System

Although the campus computing facility supports a CALCOMP drum plotter, the plotting system used by SIPS consists of a 42 x 72 inch four pen flat-bed plotter. This plotter is not an incremental type but a vector type. Plot commands are executed based upon an angle and distance input (polar coordinates). The maximum number of angles that can be differentiated is 2^{19}. Maximum speed is 10 inches per second. Plotting resolution is .001 inch. Plot tapes are normally written at the campus computing facility and read off-line by the plotter system tape drive. A NOVA 1200 with 20K bytes of memory serves as the plotter controller. Figure 5.3 is a schematic representation of the plotter system.

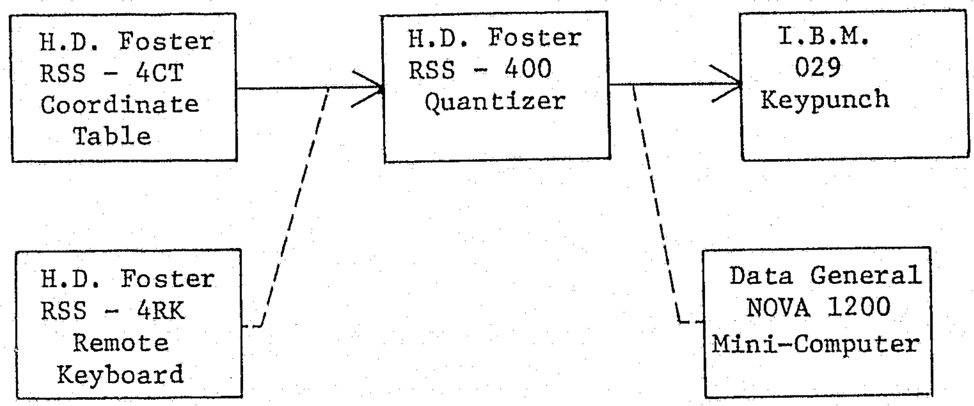

Figure 5.2

DIGITIZING SYSTEM HARDWARE CONFIGURATION

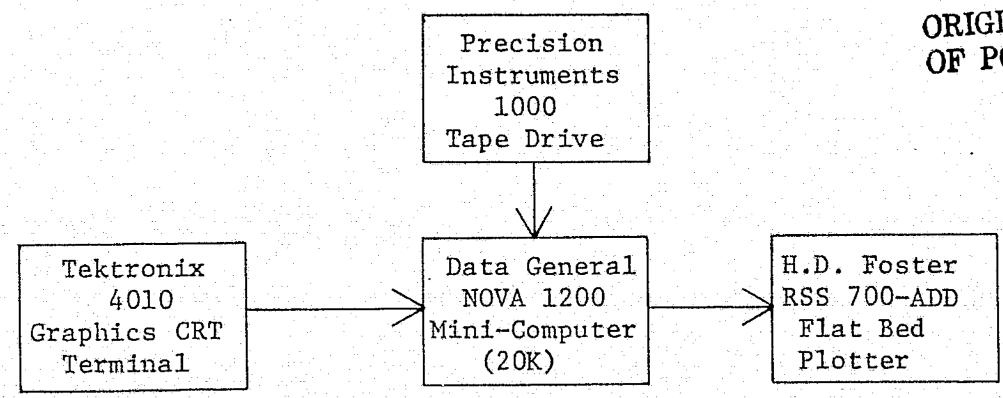

Figure 5.3

PLOTTING SYSTEM HARDWARE CONFIGURATION

Chapter 6

TRANSFERRING REMOTE SENSING TECHNOLOGY TO RESOURCE MANAGEMENT AGENCIES IN CALIFORNIA

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TRANSFERRING REMOTE SENSING TECHNOLOGY TO RESOURCE MANAGEMENT AGENCIES IN CALIFORNIA

6.1 Introduction

Now in its penultimate phase, the University of California Integrated Remote Sensing Project is in the process of preparing a retrospective survey. During the seven years of experience, the research has contributed substantially to the state-of-the-art and, incidentally, has produced many of the experts who have played key roles in vital aspects of the technology transfer process. Some occupy important positions related directly to remote sensing, others are members of user organizations, resource agencies, and industries. With the objective of encapsulating the results of the seven years' work so that they may be communicated readily and, hence, serve as guidelines to forthcoming applications, the various groups in the California Integrated Project are developing a set of manuals. The focus of much of the research was on California water, but the findings are derived from and are relevant to natural resource management broadly defined. Although the Project was one primarily of research and demonstration, rather than one that could be characterized as "user-driven", its user orientation is clear. As is to be expected, the technical specialists will focus on the aspects relating to the hardware and software, how to obtain and/or use the technology, how to interpret the imagery and apply the data it yields. In like fashion, the Social Sciences Group, which over the years has been concerned with the how and why of remote sensing in the context of resource management, is in the process of producing a companion document setting forth the social, political, and economic dimensions of this valuable real-life exercise in technology transfer.

In most cases where a new technology, or modification of an existing one, has been under scrutiny, focus has been on the what, rather than the how and why. This preoccupation with the purely technical aspects is probably based on the erroneous assumption that these are the most difficult and perhaps the most important part of the technology transfer process. The expectation is that once they are adequately developed, the rest is easy. In other words, acceptance and utilization will follow almost automatically. This view is so widespread that Dr. Frank Press, the President's Science Adviser, has criticized "technological optimists" in a series of speeches.[1] Warning against "simplistic solutions", he has pointed out the need to take into account the social environment, political ramifications, and economic consequences. In his view, there are no ultimate or singular technological fixes. Dr. Robert Frosch, similarly,

[1] As reported in Science, December 9, 1977, p. 1022.

in his keynote address before the AIAA-NASA Conference on Technology Transfer on November 9, 1977,[2] cautioned against over-simplification. Called for, in his judgment, was an appreciation of the complexities, understanding of which required more than the mere methodological Merlinism of model-makers.

Technological application, assessment, and transfer -- all three concepts more related than might appear superficially, must be observed through Dr. Frosch's lens. They are highly dependent on the social, political, and economic milieu; they bring home the harsh realization that costs, benefits, and risks are not distributed equally through a society nor do they occur within a given time frame. They remind us that we are dealing in Faustian bargains. They show up more deficiencies than strengths in our conventional kit of methodological tools for decision-making. Moreover, technology application, assessment, and transfer present an interesting paradox in that they are reflective of policy and, at the same time, instruments of policy-making.

Cognizant of the importance of the interface between remote sensing technology and the society it is intended to serve, Professor Robert N. Colwell, Principal Investigator of the University of California Integrated Project, included and continued to support research into the social aspects of remote sensing. Even when NASA technical consultants displayed lack of understanding and sometimes uneasiness about research that did not yield charts and numbers, Dr. Colwell remained steadfast in the view that the technical aspects of the transfer process of remote-sensing technology had social correlates and that to neglect them would deprive the Project of real-life dimensions and, hence, empirical test.

This is the philosophy which underlay the establishment and development of the Social Sciences Group. The current semi-annual Progress Report will serve as a review and recapitulation of the past. In presenting the groundwork for the forthcoming manual, it will link past with future and serve as a springboard as we concern ourselves with the transfer of remote-sensing technology to more and wider areas. Consistent with its long-time commitment to facilitate and implement utilization of its myriad contributions, NASA is pursuing a vigorous course in this direction. It is hoped that an in depth analysis derived from the "living laboratory" that was the California experience will provide helpful guidelines for ongoing and future projects.

The manual will be divided into four main sections: (1) the technology itself; (2) the "user community"; (3) the factors implementing and impeding dissemination, adoption, and application of remote-sensing information; and (4) the methodology of evaluation and assessment.

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[2] "Aerospace Technology Transfer to the Public Sector", American Institute of Aeronautics and Astronautics and the National Aeronautics and Space Administration Conference, Washington, D.C., November 9, 10, 11, 1977.

6.2 The Technology

The first section deals with remote-sensing technology both as an entity and in its various manifestations. The need for disaggregation becomes apparent the moment one moves from the generalized "space spectacular" mode to specific real-life applications. Here the perceptions of "the public" and "the user community", actual and potential, become determinants.* Distinctions must be made between the technology per se and its fruits, i.e., the data therefrom. This differentiation may seem obvious but it is one that is frequently overlooked by two contradictory categories: technical experts familiar with remote sensing and the lay public so totally unfamiliar that it sees either pretty pictures or colored blobs as meaningless as the inkblots on a Rohrschach Test. In other words, technical people know too much and the rest of us know too little.

Taken in its broader aspects, a remote-sensing system such as Landsat represents the coordination of orbiting satellites equipped with sensors, the hardware and software of transmitting imagery to earth, and receiving, processing, disseminating, and interpreting it. The origin and development of satellite technology are germane since they are an intrinsic part of the matrix of acceptance variables. Their history a linkage between military surveillance and space exploration, satellites carry a heritage that influences perceptions and may prejudice assessment and acceptance as well. Ancestry in the military encumbers the technology with the spy-in-the-sky taint; space parentage ascribes a pie-in-the-sky label, especially when vague promises of prowess are served up as proof of performance. While NASA enjoys public respect for having been a fulcrum of scientific and technological achievement, it also bears several stigmata: first, for being the favorite whipping boy of demagogues, short-sighted and over-zealous in their application of cost-benefit calculations to public spending** and second, for symbolizing "high", and, therefore, esoteric technology. This web of fact and fancy complicates the transfer process, which is further hampered by the ultimate necessity to justify the world-orbiting satellite system by its end-product, i.e., data. Remote sensing being in essence an information-gathering tool, the conventional paradigm calls for assessment and evaluation of that product.

But here we encounter a basic problem: how to assess the value of data. Despite the highly theoretical contributions of Marschak[3] and the earnest

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* The quotation marks used in this sentence signify that these words require and will receive further clarification. Our intent, far from pedantic hair-splitting, is to substitute functional definition for these otherwise stereotyped and amorphous terms.

** Insidious and inappropriate comparisons are made, in their rhetoric, between outer space and the inner city.

[3] Jacob Marschak, "The Economics of Inquiring, Communicating, Deciding", American Economic Review, Volume 58, No. 2, May 1968, pp. 1-18.

modeling exercise by Hayami and Peterson[4], to mention the more frequently cited references, we really do not know how to evaluate information, to say nothing of providing sensible answers to questions such as: what should be paid for it; who should pay, and the like. The final section of this report, dealing with methodology, will discuss in detail the techniques, their appropriateness and adequacy, now generally employed. Essentially, the crux of the matter lies in how the data are used.

> The evaluation of various types of information in their own terms as contributions to knowledge of value in themselves invites ... difficulty. One cannot judge where information is appropriate, or necessary, or sufficient, or excessive, except in terms of the uses to which it will be put.[5]

What ultimately counts is how the data are used -- how, whether, and to what purpose. Do they make a difference? In other words, remote-sensing technology is subject to evaluation not on its capacity to produce certain end-products but on the way those products are perceived, received, and utilized. This is a precarious position, much like judging a sewing machine by the articles which the particular operator does or can turn out! It is also an anomalous situation that the critical tests of the technology may actually lie in a future time frame and certainly outside the technical sphere. The ultimate tests lie less in the state-of-the-art than in the state of other arts (and here we especially include that of resource management).

To recapitulate, the fruits of the technology is data, but, as we indicated above, data in the abstract eludes sensible evaluation. What counts, then, is whether and how well the data are used; do they improve the decision-making process? These are basic questions, definitive answers to which become even more difficult when one considers the areas selected as "prime targets" for the application of remote sensing. The following list embraces most of these:

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4 Yujiro Hayami and Willis Peterson, "Social Returns to Public Information Services: Statistical Reporting of U.S. Farm Commodities", American Economic Review, Volume 62, No. 1, March 1972, pp. 119-130.

5 George Zissis, Klaus Heiss, and Robert Summers, Design of a Study to Evaluate Benefits and Costs from the First Earth Resources Technology (ERTS-A), Report No. 11215-1-F, Ann Arbor, Willow Run Laboratories, July 1972.

Major Applications Of Remote Sensing for Earth Resources

agriculture, forestry, range, recreation, and wildlife

soil conservation and classification
food production, forecast, storage, and disposal
irrigation management
pest and disease prevention and control
forest protection, logging, and control
range inventory and improvement
national park management
wildlife control and endangered species protection

land use

land use and natural resource inventory
land evaluation
land use assignment
development of regional land use plan
project design and implementation
planning for roads, utilities, and services

minerals, fuel, and geology

mineral and fuel inventory, exploration, forecast, and pricing
disaster and emergency action assessment and prediction (earthquakes, volcanoes, and landslides)
off-shore exploration strategy and action

water and marine resources

water resources inventory and management (household, agriculture, and industrial activities)
river basin management and development
irrigation and power production forecasts and scheduling
flood forecasting and damage assessment
ocean, lake, coastal zone, and harbor management
estuarine management
marine resources (e.g., fish) production, forecast, and control

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[6] George J. Zissis and Robert B. DiGiovanni, Remote Sensing: A Partial Technology Assessment - A User's Report, Ann Arbor, Environmental Research Institute of Michigan, 1977, p. 13.

Even though analytic description of "the user community" is relegated to another section of this report, we should note in this context that the above list points to a certain broad arena of utilization, viz., the management of natural resources. While there is no gainsaying the importance of timely and comprehensive data, this contention turns out to be more a matter of intuition and an article of faith than a demonstrable and defensible fact. Public resource management, by its very nature, is a complex composite of economics, law, history, culture, politics, power plays, sociology, policy, short-term expediency and long-term husbandry. Influenced by all of these desiderata but resisting regularized control by any one of them, public resource management is much more subject to the vagaries and vicissitudes of the social climate than to the rules of management science. As a consequence, many of the very items selected as exemplars of the "benefits" that could be realized were remote-sensing data to be used turn out to be the scene of constant controversy, where it is altogether and unfortunately likely that more or better data would make little difference or at best have little visibility in the final decisions. The focus of the manual is on California water, but an ongoing battle in Maine over the proposed Dickey-Lincoln hydroelectric project illustrates the point.

The $690-million project, which would include two dams, was originally supported by one of Maine's senators for its pork-barrel propensities and later for its energy-generating potential. But then came the classical confrontation between economy and ecology, the environmental cost of forfeiting some 30 lakes and 278 miles of streams and rivers being too high. Ranged on the opposing side was Maine's powerful timber industry concerned because 76,173 acres of prime timberland would be sacrificed. Maine's AFL-CIO wanted the project to go forward. Environmentalists claimed that the Furbish lousewort, an endangered plant, would be wiped out. (This fear was allayed and the issue faded when the plant was found to be flourishing elsewhere in Maine.) President Carter, in his attack on federally-funded water projects, cancelled Dickey-Lincoln as an economy measure; reinstatement occurred only after concerted lobbying by Maine's two senators. Since Dickey-Lincoln is designed to generate not crucial base-load, but rather peak-hour electricity, it is seen by some observers as being uneconomic, especially since more than half the 1.4 kilowatt-hours produced would be sent out of Maine to other parts of the Northeast. Not to be overlooked in the maelstrom of forces affecting the decision is the need to displace and relocate 161 families who make their home in Allagash, at the damsite.

According to the conventional paradigm, lack of information is assumed to be one of the major factors limiting "scientific" "rational" decision-making. Conversely, better information would result in improved decisions. In the case of remote sensing, there is the further assumption that the data are available and relevant. The Maine story contains many

of the elements usually present in natural resource management. The conflict and clash of interests, opposing views, jurisdictional disputes, political overtones, social and economic implications -- all enter into such decisions. The Dickey-Lincoln dam situation illustrates how very tenuous is the nexus between better data and better decisions. For this reason, along with others to be discussed in the methodology section, reliance on data usage as evidence of the contribution of remote-sensing technology is quixotic and could be counter-productive.

6.3 The "User Community"

Locating a community of "users" is a fundamental challenge for those who are familiar with the technical side of remote sensing. Although firmly embedded in the lexicon of the "technical community", the term may suggest to outsiders some sort of illicit addiction. Instead, "user" is just another example of technologists' shorthand that conveys a false sense of precision. It is an elastic catchall that is stretched to include both real and ideal technology-using possibilities. Closer inspection may reveal a "user agency" to be actually a potential user, or to contain only a solitary model manipulator or part-time student whose duties might be construed as putting the technology to use. The word has additional ambiguity when mixed with the vocabulary of governmental agencies who consider themselves to be working for a clientele of users, or when it refers to technical community members who "use" remote sensing data in their research projects.

Recognition that the "user" rubric is a single concept representing a continuum of realities helps explain some of the apparent gaps between the words and deeds involving remote sensing applications. In the water resources area most organizations considered part of a remote sensing user community more appropriately could be described as "potential users". Yet even this term has its gradations, as Integrated Project participants have seen. Several years' involvement in research projects can change remarkably the disposition of a potential user agency toward a new technology. How far along the agency comes in actually using the technology depends on a huge number of factors -- political, economic, behavioral, and others.

Profile of Users and Uses

Sales of Landsat data from the EROS Data Center in Sioux Falls give clues to the composition of the remote sensing user community. A profile of orders for 1976[7] showed the largest dollar volume of data products were

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7 Joan Davenport, Assistant Secretary for Energy and Minerals, Department of the Interior, statement before the Subcommittee on Science, Technology, and Space, Committee on Commerce, Science and Transportation, U.S. Senate, Hearings on S. 657, May 24, 1977, p. 67.

purchased by private industry and federal agencies (22% and 21%, respectively). Orders from non-U.S. customers and NASA principal investigators were the next largest categories (17% and 16%, respectively), with the remaining orders coming from individuals, academia, and state and local government. One can argue about whether EROS data sales provide an appropriate user index or whether the EROS categories fairly represent the user population, Nevertheless, it is possible to sketch portions of a user profile that approximates reality. Industrial users, particularly those in the business of extracting petroleum and minerals, are probably making the greatest "use" of remote sensing data products today. Satellite-derived information is viewed as a new "prospecting" tool, especially valuable in upgrading surface geological maps. Users interested in the data for applied research purposes comprise another large class. LACIE[8] is by far the largest of a group of many projects that are geared toward a sort of "usage" that is tentative and experimental. Some "users" are mainly collectors. Agencies and foreign governments sometimes maintain standing orders for imagery even if they have no immediate use for it, while individuals, urged on by magazine advertisements, may simply wish to see satellite photos of their home town.

Uses of remote sensing information, like the users themselves, can be placed along a continuum ranging from simple to complex. One pre-Landsat hierarchy of uses is still applicable today.[9] It characterizes progress toward applications objectives in six stages of activity: <u>identify</u>, <u>map</u>, <u>monitor</u>, <u>model</u>, <u>predict</u>, and <u>manage</u>. Within this framework, the mapping activities of users in extractive industries constitute intense development of relatively simple applications. The intensity of this use will likely decline once most important geologic areas are well-mapped. Applications to dynamic resource phenomena like crop production are examples of relatively complex uses that still require a lot of development work. Monitoring functions, in general, represent a level of use several magnitudes more complicated than basic identification and mapping activities.

This distinction between types of uses helps explain the reluctance of resource managers to commit themselves prematurely to a still speculative source of information. Complex applications need extended development time, and users have little assurance that existing federal earth resources programs will continue much beyond the technology demonstration

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[8] Large Area Crop Inventory Experiment (LACIE) is a multi-year joint project between NASA, the U.S. Department of Agriculture, and the National Oceanic and Atmospheric Adminstration that aims to test the effectiveness of Landsat in delivering information useful for predicting global crop production.

[9] Zissis, Heiss, and Summers, <u>op</u>. <u>cit</u>., p. 37.

phase. Implementation of new procedures also requires the aid of specialized equipment and trained personnel. Furthermore, many adjustments must be made before satellite-derived information can blend with the decision processes of most natural resource managers. The interest of different types of data users complicates the adjustment process. Generally, scientists involved in research are inclined to want relatively unmolested data so they can draw their own conclusions about discrepancies. Resource managers, in contrast, prefer to have their data reduced to bear directly on decisions confronting them. Extraneous information only confuses their tasks.

State and Local Users

Reconciliation of differing applications objectives and information requirements becomes easier with experience. Of the user groups capable of providing broad ranges of experience, few can offer a greater variety of resource management functions and approaches than state and local governments. Yet to justify the expense of technology demonstrations solely on the breadth of experience to be gained is rather tenuous. Development of state and local user interest in remote sensing applications is important for two other reasons as well: (1) cooperation of non-federal governmental units is indispensable in many national resource planning efforts, and (2) state and local agencies provide a vital forum of linkage between resource policy questions and public response.

The first point should be apparent to anyone who follows intergovernmental relations and resource issues in this country. Many state and local agencies harbor suspicions about each other, but they usually distrust federal government agencies even more. State and local agencies are especially sensitive to federal incursions into what they consider to be their discretionary domain over natural resources. Prolonged jurisdictional battles and court cases can follow seemingly minor changes in policy or regulations. Federal plans concerning energy, water, timber, agriculture or other resources can become emasculated without the support of other governmental levels. Remote sensing, often viewed as a means for integrating diverse bases of resource information, is subject to similar pressures. If centralized only within the planning apparatus of large federal agencies and industrial organizations, the technology will fail to achieve its potential as a useful tool.

The second point buttresses the first: public resource planning should involve the public and this is best accomplished through lower levels of government. Mistrust between governmental units is insignificant when compared with public mistrust of all levels of government. In many circles, governmental planning of any sort is viewed as outright "socialism". Also, people correctly perceive that most government efforts to include the public in their planning processes are a sham. The question asked most often by the citizens that attend such meetings usually is: "What are your plans going to do to me?" If remote sensing is to overcome its association in

the public mind with "spy satellites" and expensive space "spectaculars", then it needs to be integrated with resource planning processes at the grass roots level of state and local government.

Accomplishing this degree of integration, if our experience is a guide, requires a full-time effort that extends over many years. The point has not been lost on California state officials who are familiar with the experiences of various state agencies in applying remotely-sensed information. William L. Kahrl, of the Governor's Office of Planning and Research, described at a recent workshop for state legislators some of the realities involved in transferring Landsat technology to California agencies[10]:

> The problem of achieving ongoing applications of Landsat technology involves not the adoption of a system but the conversion of our existing systems. For this purpose, it is probably not sufficient that the technology is economical; it must be inexpensive enough to justify trashing another system. It is not sufficient that the technology be useful, it must be uniquely so. It is not sufficient that the technology is simply efficient, it must be better than what we are doing already.

California's water resource, as emphasized early in the Integrated Project, provides an excellent vantage from which to scrutinize remote sensing applications. "Water," Leonardo da Vinci once observed, "is the driver of nature." In California especially, it is also a driver of human affairs. The importance of water in natural resources and social processes helps extend the validity of lessons learned while applying remote sensing techniques to water supply and demand problems. Although the water resources applications dealt with in the Integrated Project are but a tip of a much larger R & D iceberg,[11] we feel many of the resulting insights can

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[10] William L. Kahrl, Director of Research, Governor's Office of Planning and Research, State of California, "Overview of California's Approach to a Statewide Remote Sensing Program," address delivered to the National Conference of State Legislatures Remote Sensing Workshop, Cal-Neva Lodge, Lake Tahoe, November 8, 1977.

[11] See, for example, American Water Resources Association, Remote Sensing and Water Resources Management, Urbana, Illinois, June 1973; and Albert Rango, "Applications of Remote Sensing to Watershed Management", Goddard Space Flight Center document X-913-75-86, Greenbelt, Maryland, June 1975. Experimental applications and demonstrations of earth resources satellite capabilities include among others work in snow mapping, flood assessment and floodplain mapping surface water inventories, hydrologic land use analysis, physiographic characterization, watershed modeling, and determination of soil moisture.

be of use in future projects designed around user needs. In the remainder of this section, we examine those insights that deal with agency information requirements.

Information Requirements

The sort of information required by water managers (or by any other resource mangement activity, for that matter) follows directly from the kinds of problems and alternative solutions perceived and from the various risks, uncertainties, and constraints present. And increasingly the sorts of problems water managers must face are tangled with issues concerning energy consumption, food and fiber production, land use and transportation policy, environmental protection, and social justice. The decision choices of water managers, in other words, affect a wide range of people and groups with interests that transcend basic water development and operation issues. Such groups understandably place differing values on the consequences of alternative decisions. Since different groups of advocates have varying access to the decision-makers and their information concerning consequences, water managers find themselves pressured to develop and test planning systems using information that is more comprehensive, publicly visible, and "value-neutral".

Broader objectives and multidisciplinary planning requirements thus provide many of the stimuli to investigate new techniques for handling water planning information. The availability of large-scale data handling capabilities is another stimulus. Computer models that simulate physical, economic, and environmental conditions can be found within most of the larger water management agencies, although agreement on their utility is harder to find. A typical situation might reveal a coterie of modeling enthusiasts at one end of the organization, experimenting continually with variations on a modeling scheme, and ranks of justifiably sceptical veterans at the organization's other end, who place their faith in tried-and-true "guesstimation" procedures. Meanwhile, the agency relies on a variety of basic information just to get through year-to-year operations: meteorological and hydrological data concerning snowpack, runoff volume, and stream flow variability; geologic and vegetative characteristics of watersheds; water use and water quality data for irrigated agriculture, recreation, and other uses; soil moisture and ground water variations; and flood potential and damage extent should flooding occur.

Zealous members of the remote sensing community look at the information requirements of water management organizations and see their satellite data blending harmoniously with terrestrial water models. Such optimism overlooks several facts of life within the agencies that use such models, namely that:

(1) Watershed models capable of using satellite information are in very preliminary stages,
(2) Implementation of any major water model takes many years,
(3) It is often difficult to get the right people interested in new data manipulation methods,
(4) Few agency personnel are likely to be familiar with remote sensing techniques,
(5) Most remote sensing digital equipment is expensive by agency standards,
(6) Operating costs for analyzing large areas are also relatively high.

Much of the work performed under Integrated Project auspices illustrates that there are ways to surmount these problems. Small-scale research demonstrations are often able to penetrate organizational interstices that would impede larger projects. More importantly, continuing involvement over a period of years nurtures a deeper understanding of the problems and possibilities in transferring new methodologies. In terms of information requirements, our lessons are derived from three applications examples: snow survey work of the California Department of Water Resources (DWR), the Kern County Water Agency's water demand modeling effort, and general management concerns about drought conditions.

° Snow survey. One of the greatest dilemmas facing a manager of snow survey operations is deciding which technological baskets should carry his scarce supply of eggs. DWR's Snow Survey Branch employs a well-established watershed indexing system, based on samples from snow courses and aerial markers, but it also is experimenting with modeling systems which use satellite photos and computers. The objective of the program is to provide water system operators with timely runoff information that will allow them to assess their risks better. Yet even with the best possible information, uncertainty about future weather accounts for the greatest source of error in forecasting the snowpack's "rate of ripening". In commenting upon Integrated Project work on snow water content measurement, snow survey experts acknowledged that the statistics developed often told more about the hydrology involved than the forecasts. Multidate analyses of watershed characteristics will reveal areas of variability within snow water content strata, thus making it possible to allocate more judiciously snow courses. Ground substantiation is likely to remain one of the more costly elements of snow survey work, regardless of whether indexing or continuous modeling methods are employed.

° Water demand modeling. Managers of large farming operations often would like to know what alternatives could be achieved given greater water demand prediction abilities. Their decision problem in terms of remote sensing could be stated thusly: What would more accurate,

more timely, and less costly information on water usage allow them to achieve? Should they inject, spread, or sell the water? Should more land be brought into production? If so, in what crops? The Geography Remote Sensing Unit's work on salinity and perched water in Kern County[12] has shown also that farmers often lack information on the real extent of such problems, and would like to know where to bore wells and locate canals.

Drought. The severity of California's recent drought[13] revealed both water managers and farmers to be among the world's biggest gamblers. With the state's massive water system nearly depleted, many farmers had to drill deeper into rapidly declining water tables. Drought-weary water managers and farmers are obviously more interested in replenished water supplies than in satellite data. Yet when asked directly about the information requirements, those in the business of maintaining state irrigated agriculture are fairly specific: they would like to know how many acres are planted; how much water is available from surface, soil moisture, and groundwater sources; how much water is used; and what the health status is of the state's fruit and nut trees. Current information on these categories is especially useful in assessing the effects of a drought.

6.4 Factors That Implement and Impede Technology Transfer

If technology is the systematic application of scientific knowledge, then technology transfer is the sum of those activities through which the knowledge is applied to resolve problems. Technology transfer has been described by one agricultural researcher as "a complicated process, interlaced with communication strings, shaped by a continuum of knowledge, and pulsating with research findings and user demands.[14] The Integrated Pro-

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12 See John E. Estes et al., "Remote Sensing Detection and Monitoring of Perched Water Tables in Kern County," Chapter 3 in Robert N. Colwell, An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques, Semi-Annual Progress Report, NASA Grant NGL 05-003-404, Space Sciences Laboratory, University of California, Berkeley, May 31, 1976.

13 For further description of the drought, see: State of California, Resources Agency, Department of Water Resources, The Continuing California Drought, August 1977; Anne Jackson, "How California Life will Change as a Result of Two Parched Years", California Journal, April 1977, pp. 111-122; and Ida R. Hoos and James M. Sharp, "Impacts of the Drought on Water Management in California - A Socioeconomic View", Chapter 6 in Robert N. Colwell, op. cit., May 31, 1977.

14 K.E. Saxton, "Technology Development and Transfer for Natural Resources Management " Journal of Soil and Water Conservation, May-June 1977, p. 124.

ject, viewed in its entirety, can be seen as a continuing effort in technology transfer. It comprises parallel threads of research, research assimilation, and application of research to California resource problems, particularly in the water area.

Often the transfer process is viewed as a vehicle through which research investments are converted into social payoffs, usually measured in economic terms. In the case of water resources research, however, the majority of new technological developments have few immediate and readily demonstrable payoffs.[15] Experience from the Integrated Project only superficially confirms this observation. Evidence of large payoffs are not yet visible in the current operating budgets of those agencies who have been project participants. Nobody really expected them at this time. Yet it is relatively easy to identify higher-order payoffs represented by individuals whose knowledge, capabilities, and careers have been changed by association with the project. This sort of "person-embodied" technology transfer is essential if an ongoing program of use to resource managers is to be sustained.

In addition to the human element, remote sensing also contains portions of "product-embodied" and "process-embodied" technology. Outside of specialized data reduction and image enhancement hardware, the product component of remote sensing needing transfer is small. In contrast, transferring the process by which useful information is extracted from raw data can be a large task, depending on the application involved. Usually the direction of transfer makes a difference on what is transferred. Some of the Integrated Project's findings have been transferred horizontally, between research groups, while most efforts are aimed at vertical transfer, directed from research toward application. The fact that application of research findings almost never is achieved in a single step explains why technology transfer is considered a process. The process through which an innovation is communicated from one individual to another through an organization is termed "diffusion". Correspondingly, the procedure by which new information is actually perceived, internalized, and used has been termed the "adoptive process". This has been portrayed as involving five stages along a learning curve consisting of (1) awareness, (2) interest, (3) evaluation, (4) trial, and (5) adoption.[16]

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15 Universities Council on Water Resources (UCOWR) Technology Transfer Committee, "Water Resources Technology Transfer, A Guide", available from the Office of Water Research and Technology, U.S. Department of the Interior, Washington, D.C., January 1977, p. 6.

16 UCOWR, op. cit., from Everett M. Rogers, Diffusion of Innovation, The Press of Glencoe, New York, 1962.

Sometimes preceding and usually following technology transfer is the process of "information dissemination". While this activity is aimed at stimulating user receptivity by creating an awareness of the new technology, it can backfire when poorly handled. "Full dissemination and use of research," according to a recent Office of Water Research and Technology report, "requires an understanding of social systems by technology transfer specialists and prospective users, and is necessary before effective communications of new research and innovation can occur."[17] Throughout the Integrated Project, our Social Sciences Group has attempted to provide this kind of understanding. In the remainder of this section we discuss several topics aimed at promoting understanding of remote sensing technology transfer processes as we have observed them. We consider, in order, preconditions for successful technology transfer; elements which help implement technology transfer; impediments to transfer, both user-related and technology-related; and potential pitfalls.

Preconditions for Transfer

Even a cursory exposure to remote sensing applications is sufficient to learn that the technology will not transfer itself. It is occasionally complex, it sometimes requires specialized equipment, the people doing it require special training, and each application must be tailored to fit the user's particular problems. Nevertheless, one does not have to look far to find examples of applied remote sensing research that assume away such difficulties. Excessive preoccupation with the technical "trees" of applications can obscure whole forests of resource problems. And since problem resolution is the usual end product desired from the application of new knowldge, familiarity with a user's information requirements and decision processes is essential to direct the technology toward real problems. The whole transfer process is greatly facilitated, in other words, when technology transfer objectives are coincident with the user's perceived needs.

A closely related precondition for successful transfer is the user's stake in the effort. In those cases where the user has a vested interest in a positive outcome, the transfer effort is likely to proceed more smoothly. Such an interest may be created when the user agrees to contribute personnel, facilities, or other resources to the project, or when the user is able to participate directly in selecting the area for technology application and in evaluating the resulting outcome. Projects within the Integrated Project, for the most part, have attempted to demonstrate how state-of-the-art remote sensing research can be adapted to problems faced by water management agencies. Applications with more of a "user-driven" orientation, in contrast, normally allow user problems to guide selection of the appropriate level of technology.

[17] UCOWR, op. cit.

Obviously, users are likely to have greater interest in participating in demonstrations of technologies they already know something about. With remote sensing techniques especially, early user awareness can greatly expedite successful applications. Initial exposures to the technology may come about through deliberate information dissemination, or by reputation from the experiences of other users. In any case, progress from a state of awareness to a state of interest and eventual involvement is much assisted by motivated individuals within the user organization. These people are often ahead of their associates in formulating problems and asking the appropriate research questions. Their key role as intermediaries between general technical information and specific applications of it in new operations has earned them a reputation of "technological gatekeepers".[18] User organizations fortunate enough to employ even one such individual have significant advantages in shortening their path toward successful transfer of a technology like remote sensing.

Implementing Elements

Attention to the right factors can often reduce the distance between promising innovations and useful applications. We consider here a cluster of elements which affect remote sensing implementation efforts. These elements are really multidimensional labels that reduce to near platitudes if described in just a single dimension. Most everyone will agree, for example, that sustained person-to-person contacts between technology developers and users are essential to successful transfer efforts. Similarly, each element has its reciprocal: if improved communication linkages foster transfer processes, then the same processes are likely to be inhibited without them. All these elements acquire greater meaning when qualitative dimensions are added.

- Communication. Feedback between participants is vital for sustaining transfer of an information technology like remote sensing. Tailoring applications to a user's unique information parameters is a job that requires intense communication in a variety of modes. Personal contact is clearly indispensible for establishing and nurturing the sort of credibility between individuals needed to transfer complicated technologies. Geographical arrangements often determine how personal contacts are made and maintained. Other media are also useful for transferring research findings but they must fit the target audience. Public relations media -- news releases, magazine articles, broadcasts, and the like -- are geared to general audiences, whereas newsletters, trade journals, displays, and seminars are more appropriate for specialized audiences.

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18 See: Thomas J. Allen, et. al., "The International Technological Gatekeeper," Technology Review, March 1971, p. 1, discussed in Dennis Goulet, "The Paradox of Technology Transfer," Bulletin of the Atomic Scientists, June, 1975, p. 45; and Edward B. Roberts, "Generating Effective Corporate Innovation," Technology Review, October-November 1977, p. 27.

User manuals, such as those associated with the Integrated Project, are even more detailed and specific in content. Specialized manuals are usually insufficient by themselves as communication tools. They have greater utility when incorporated into technology transfer "packages" that include additional support and technical assistance. All these communications, regardless of intended audience or medium, are benefited if simplicity becomes their guiding principle.

- Coordination. Establishing a means for coordinating technology transfer activities involving governmental agencies becomes a necessity in larger projects. A transfer process left to the coordinating abilities of individual researchers may be too speculative for many users. The wide variety of possible coordinating configurations -- ranging from outside task forces to in-house top executives -- suggests some of the attributes needed for the role. Above all, such individuals should be effective translators, capable of bridging the gaps between researchers and users. Moreover, it helps if they possess sufficient authority and technical knowledge to make the kind of decisions required to keep demonstration projects "on track". A mixture of pragmatism and ingenuity is also an asset. An Office of Water Research and Technology report describes the coordination function in mechanical terms[19]: "A transfer program may be likened to a gear-wheel whose cogs must mesh with several other gear-wheels which are already in motion. The program gear-wheel must be turning at the correct speed to achieve correct meshing without clashing."

- Continuity. It takes time to put into place an effective apparatus for communicating and coordinating a process for technology acceptance. Even then, it may still take years before a technology like remote sensing will begin to bear fruit. Disruptions in personnel and support along the way can undermine credibility and morale. Avoiding discontinuities in a long-term program of technology transfer can be made even more difficult by the normal political and budgetary cycles. The extraordinary length of such processes may obscure their endpoint. "The transfer of a technology will be completed," according to one researcher,[20] "when the technology becomes generally accepted practice, or when the chief officer of a governmental unit routinely assesses available technology when presented with a problem, or when the technology is readily available in the marketplace."

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19 UCOWR, op. cit., p. 17.

20 Charles F. Miller, "Some Approaches to Transferring Federal Technology to State and Local Governments: The Lawrence Livermore Laboratory Experience," Proceedings of the National Symposium on Utilization of People-Related Research, Development, Test and Evaluation, San Diego, California, June 14-17, 1977.

- Competence. This quality is closely associated with the others. Involvement of competent individuals in technology transfer efforts is essential for maintaining credibility. User personnel who have no one to turn to when they encounter application problems, or who suspect their technical consultants do not really know what they are talking about, are less apt to embrace a new technology. Competency is thus one of those intangibles that is easier to recognize than to define. A competent technology transfer specialist no doubt will possess a combination of technical and general skills. Strong communicative abilities and an understanding of how to motivate a variety of personalities are necessary attributes. These must be mixed with sufficient patience and dedication to get the job done.

- Commitment. No technology transfer process can succeed without commitment and support from a variety of directions. Commitment from political leadership is one of the most useful sources of support, but one of the most difficult to achieve. Legislators, in particular, often fear that natural resources data collection systems will turn into "bottomless pits". Securing the commitment of top administrative leadership within the agency can also greatly assist a transfer effort, but without sufficient "fires" already ignited within the organization's lower levels, there is unlikely to be any "smoke" at the top. Financial commitment from either within or outside the agency is important for sustaining the effort, although agency-contributed resources tend to generate greater user participation for the money. The commitment of technical expertise is another essential ingredient. Normally coming from outside the user organization, technical support requires careful supervision to keep costs in line and work consistent with user information needs. Finally, the moral support engendered by similar commitments of other agencies working on parallel transfer programs can be an extremely beneficial catalyst. Regular information exchanges between different user groups helps spread both technical and non-technical insights and maintain a continuity of interest.

User-Related Impediments

Once a transfer process has begun, there are a host of other conditions that influence user response toward the new technology. Here we consider one set of issues that can impede or deny success to any technology application effort: agency insecurities over the possible side effects of including remotely-sensed information in their operations. These considerations point up the subtle distinction between evaluation of a technology's results and the more comprehensive notion of technology assessment. They frequently escape more formalized evaluative procedures because they possess poor visibility, defy meaningful quantification, or both. Yet failure

to assess and anticipate adequately such "intangibles" can be disastrous for a technology transfer effort. Implementation of any of a variety of remote sensing information systems, from the viewpoint of water managers, particularly, might be expected to raise concerns about the following sorts of changes:

- Changes in activities. Familiarity with an existing method of producing resource management information can breed contempt for new methodologies. Snow surveying work, for example, still makes occasional use of men who ski through winter snows to collect snow water content measurements. Likewise, DWR agricultural inventories require substantial field work that would probably be reduced in satellite-based systems that use sophisticated sampling techniques. For those who prefer outdoor rigor and "windshield surveys" to stereoscopes, the activity changes associated with remote sensing could diminish job satisfaction. Concerns of this type are best dealt with by implementing changes gradually.

- Changes in budget. The possibility that any savings generated by new methods would result in reduced budgetary discretion is a concern very real to agencies exploring new technologies. Such fears are likely to be exaggerated, however, since new methodologies usually require a series of budget years to achieve implementation. Probably greater budgetary dislocations are caused when outside support for experimental programs is withdrawn. Money and personnel "bootlegged" from temporary sources are often used by resource management agencies to supplement relatively inflexible budgets.

- Changes in equipment. Certainly not all remote sensing approaches are immune from "people versus machine" controversies that accompany many high technology applications. Yet of the applications investigated under the Integrated Grant, most are designed to mesh with existing agency methods with a minimum of equipment changes. The manual method of snow areal extent estimation, for example, divides the resource photo into grid cells for manual interpretation. The procedure is compatible with machine-aided classification methods when and if they should be desired. Proposed crop inventorying procedures follow a similar tact: outside of extra stereoscopes and acetate overlays, they use very little equipment or material not already used by DWR in their own surveys.

- Changes in information. Agency concerns that a new technology will be unable to deliver new information in the old format are frequently justified. A system for performing a statewide inventory of agricultural acreage in a single year, for example, would no doubt require broader land use categories than the less frequent but more detailed system now used by DWR. Advantages and disadvantages of changes in information scope and detail must be examined on a case-by-case basis.

- Changes in jurisdiction. A related issue involves the possibility that new information combinations might alter existing jurisdictions over information sources. Since water resource and land use information is common to several state agencies, changes initiated by one agency sometimes can affect the others. Efforts to consolidate the information-gathering activities of state agencies undergo periodic revival[21], and it is probable that the increased availability of synoptic data will encourage greater consolidation in the future.

- Changes in public image. Any agency making greater use of imagery from earth resources satellites and U-2s should be prepared to encounter public fears about "spy-in-the-sky" surveillance. NASA's civilian space technology is rich in a military heritage that for some people transfers guilt by association to those organizations that make use of it. Farmers are often among the first citizens to voice their concern that remotely-sensed information will invade their privacy.

- Changes in skills. Increases in photo intrepretative and statistical skills are almost always required to use remote sensing techniques to an advantage. Such skills are transferred through training and practice -- there are no shortcuts to competency. Fortunately, when agency personnel are already familiar with aerial photographs of resources in their respective areas, the skills transfer tasks can be simplified.

Technology-Related Impediments

User agency concerns over changes that might accompany the adoption of remote sensing techniques are one category of impediments to technology transfer. Another category relates more directly to characteristics of the technology itself. These factors can be equally influential in determining a user's receptivity to applications involving remote sensing. We list them here:

- Complexity. This point can be summarized in the axiom: "If they don't understand it, they won't use it." A user organization's pace of learning or adoption of the technology is governed by that technology's complexity.

- Specificity. The technology applications must specifically address problems faced by the user. An elaborate "mousetrap" will be of little use to an organization with plenty of standard traps or no mice. In addition, new technologies must prove themselves

[21] See, for example, Legislative Analyst, State of California, "Water Resources Planning and Agricultural Water Needs," January, 1973.

along the way, and the "proof" must be fairly tangible in a relatively short time.

- Availability. This term concerns the efficiency of the technology's delivery system. The speed of data availability can be critical for users with applications dealing with transient phenomena like snow areal extent or crop acreage. Unavailable or untimely data can subvert progress achieved in adapting new methodologies to user needs.

- Reliability. This concept has a dual meaning: it refers to the quality and consistency of the data as well as continuation of the data source. The second meaning lies at the core of the earth resources data "chicken and egg" problem where users are reluctant to use the data unless they can be assured of its continued availability, and where federal support for additional earth resources satellites is contingent on demonstrated user acceptance.

- Accessibility. The reference here is not to the efficiency of the delivery system but to its openness of access. Prospective users invariably ask about the secrecy associated with the gathering and dissemination of Landsat-type data. They usually are relieved to find that unlike publicly-accessible military satellite data which require detailed personal security checks, obtaining data gathered by civilian satellites is no more difficult than ordering from mail-order catalogs. Freedom of access is axiomatic as a condition for receptivity.

- Compatibility. Potential users often are reluctant to try out new data sources if they are incompatible with familiar decision models. Compatibility is particularly important when the user is attempting to blend multiple sources or uses of data.

Potential Pitfalls

The negative counterparts of the elements which help implement transfer attempts are most visible when the attempts are viewed in hindsight. We see them as potential pitfalls for most remote sensing applications that involve governmental agencies. Along with the user- and technology-related characteristics that influence receptivity, the pitfalls can be grouped among those elements that impede technology transfer.

- Oversell. Supporters of many new technologies run the risk of raising user expectations to levels beyond what current applications can deliver. No linguist is needed to note the increase in praiseworthy words used to describe the technology as one ventures up through the administrative hierarchy -- and away from

the user application level.

- Overkill. This pitfall is related to the complexity problem and user concerns about changes in equipment. It often involves cases where sophisticated digital classification capabilities are prematurely applied to resource inventory problems. A "computational imperative" is thus thrust upon an agency that has yet to grow comfortable with manual interpretation techniques. A solution for cases like this are sequences of smaller projects emphasizing fundamental principles in manual formats that can be easily adapted to computerized methods, when and if they are needed.

- Undertraining. The scarcest resources in most remote sensing applications are properly-trained personnel. Unfortunately, there are no shortcuts available for creating more of them. No amount of half-day minicourses or two-week workshops can substitute for experience gained over several years of direct involvemnt in applying remote sensing imagery to resource problems. Furthermore, different types of training are needed for different resource disciplines and for the various functions within them.

- Underinvolvement. An agency's ambivalence or lack of sufficiently qualified or motivated personnel may seriously handicap their participation in demonstration projects. Situations like this can cause agencies to turn over too much of their project to consultants or others who lack familiarity with the agency's resource problems and information needs. The risk here is that the agency will treat the outside data manipulations as a "black box", accepting or rejecting the resulting outputs uncritically. Not only does the underinvolved agency learn little in this process, but it may overlook sources of error that could have been easily eliminated.

- Spurious evaluation. Agencies participating in remote sensing applications can sometimes find themselves caught up in a "rush to judgment" encouraged by powers far removed from the technology implementation phase. This situation can produce premature, incomplete, and incestually-validated evaluations of little use to anyone, especially the user. Agencies are very sensitive about numbers that publicize how poorly their existing information system fares next to an experimental model. Rarely are new technologies subjected to the more comprehensive assessments they deserve.

- Misapplication. This pitfall is a variation of the "hammer-nail problem" wherein everything begins to look like a nail if the only tool you have is a hammer. It occurs most often in cases where the user and technologists have failed to anticipate areas where the technology can be advantageously applied to solve genuine problems.

6.5 Methodology of Technology Evaluation and Assessment

Isolation of a community of users and articulation of their information needs are merely prerequisites in actually applying a new technology. A full range of technology transfer issues must be resolved before any progress can hope to be achieved. These include a determination of the user's state of readiness and receptivity conditions, identification of key individuals and sources of support, and selection of appropriate methods for communicating, coordinating, and evaluating introduction of the technology. All these issues, particularly that of evaluation, are related to the larger discipline of technology assessment.

To call technology assessment a "discipline", however, runs the risk of endowing it with more maturity than it actually possesses. Though the methodology has undergone considerable evolution within the last decade, technology assessment is still in its infancy. It is really an amalgam of techniques borrowed mainly from operations research and systems analysis. As a result, technology assessment basks in a borrowed glory because of a prestigious heritage in defense and space management. Most of the discipline's applications have centered on narrowly-construed problems in military, public works, or business domains. All too often weighty conclusions are supported on a fragile base of deceptively precise benefit-cost calculations. The failure of such studies to inquire about wider social costs and benefits and their incidence on various publics sometimes leads to unfortunate effects, including popular backlashes against engineers, scientists, and public officials.

Experience with the earlier generation of technology assessment efforts has prompted a reconsideration of their role. A more mature approach is emerging that includes, for one thing, a growing consensus on what a comprehensive technology assessment should be:[22]

(1) Any assessment implies a comparison of advantages and disadvantages of a specific project or technology.

(2) A technology assessment consists of two complementary and closely interweaving processes: forecasting and evaluation.

(3) The object of a technology assessment is to distinguish between a technology's desirable impacts, undesirable impacts, and uncertainties.

(4) A comprehensive technology assessment attempts to consider all relevant aspects of a technology's impacts on society. It includes first-, second-,

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[22] Francois Hetman, Society and the Assessment of Technology, OECD Publications, Paris, 1973, pp. 350-390.

and third-order impacts as well as impacts on various constituencies.

(5) Technology assessment is a multidisciplinary approach, it is iterative, and it is an instrument of policy making.

For another thing, there is increasing sophistication concerning the limitations of the assessment methodology. Technology assessment and its chief evaluative underpinnings (cost-benefit and cost-effectiveness analysis) share several of these characteristics:

(1) They are social advisory activities and do not by themselves produce policy decisions.

(2) They are filled with value judgments and assumptions.

(3) They cannot be routinized.

(4) They depend on a continuous evaluation of the state of society, since rapid changes in socioeconomic conditions can upset many of their underlying assumptions.

A heightened awareness of the inherent limits of quantitative analysis underlies much of the shift in attitude concerning assessment methodology:

> Unhappy clashes with aroused groups of ecologists have proved that when a dam is being proposed, kingfishers may have as much political clout as kilowatts. How do you apply cost-benefit analysis to kingfishers?... In the long run the entire Cartesian assumption (that there are measurable and incommensurable quantities) must be abandoned for recognition that quantity is only one of the qualities and that all decisions including the quantitative, are inherently qualitative.[23]

Also, there is realization that search for a single method for performing assessments has been misguided: "The broad category of systems analysis is likely to be the central theme in any assessment. But there is no general method, methodology, or techniques yet developed for conducting a technology assessment."[24] Moreover, there exists little assurance that different assessments will produce similar conclusions: "Since the specific methods for determing the unintended, indirect, and delayed social effects of a given technology are diverse, unrigorous, and judgmental, different teams of equal competence are likely to generate different technology assessment results -- different in emphasis and usefulness to decision makers."[25]

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23 Lynn White, Jr., "Technology Assessment from the Stance of a Medieval Historian", Technological Forecasting and Social Change, 6, 1974, p. 360.

24 M.J. Cetron and B. Bartocha (eds.), Technology Assessment in a Dynamic Environment, Gordon and Breach, New York, 1973, p. 285.

25 Zissis and DiGiovanni, op. cit., p. 15.

If nothing else, continuing maturation of approaches to technology assessment has produced a new humility regarding the interaction of technology and the complex systems that encompass man, society, and the environment. Increasingly, technology assessment is viewed as a means of obtaining some insights about the application of technology to some elements of such systems. Comprehensiveness is impossible; routinized approaches to different problems are unrealistic. A well-conceived technology assessment may overcome the obvious limitations of a narrowly-defined impact study or an overly-precise benefit-cost analysis, but it too will have limitations. Nonetheless, an improved understanding of new technologies and their effects on social and physical systems is essential to avoid in the future many of the problems and mistakes of the past. Even though we may not know how to assess properly a proposed technological change, that should not prevent us from trying.

It is no accident that much of the evaluative foundation of assessment methodology was built around water resources problems. Governmental operations in the water resources area were deemed analogous to those of private enterprise since the principal outputs of water projects-- water and power-- are salable commodities bearing market prices. Not long ago, evaluation of such projects meant assessing their contributions toward objectives such as irrigation, reclamation, hydropower generation, flood control, water transport, and municipal and industrial uses. These objectives in turn often were collasped into a single overall objective, measurable in terms of contributions to net national product. Intangible project impacts, those not readily translated into monetary units, either were neglected or minimized. Shifts in social priorities have thrust some of these second order impacts into greater prominence. Project evaluation today often means assessing contributions to such additional objectives as outdoor recreation, regional development, wildlife conservation, scenic enhancement, and income distribution. No single standard of value, monetary or otherwise, can fit all objectives.

Assessing the contributions of an information technology like remote sensing in a resource management area like water resources further expands the evaluation complexities. Decisions, decision-makers, and decision-makers' objectives lie at the heart of the matter. What ultimately counts, as we mentioned before, is how the data are used to improve decisions. Especially critical are assumptions concerning the extent of impacts expected from the investment in questions, what impacts and affected groups lie within these boundaries, and how the impacts are valued. An understanding of the decision processes at work within the affected resource management agencies can do more than illuminate these evaluation issues: it can also help in designing a technology transfer program compatible with the objectives of the organizations involved.

User objectives and decision processes are thus common denominators for approaching both technology assessment and utilization questions.

The qualitative elements within these processes often are far more useful to resource managers than quantitative information. For example, information concerning the volume of potential runoff contained in a snowpack is of little use to a water manager with a reservoir nearing capacity. He must decide whether or not to open the spillway, when, and for how long. What the manager really needs is information that allows him to assess better his risks in marginal cases. This implies an improvement in the water manager's capability to handle improved forecasts. Decision-makers at the operational level, in other words, are looking for better information on the consequences they face while pursuing alternative courses of action.

The parallel objectives of better technology assessment and technology utilization can be served best by involving the decision-makers throughout the entire process of technology development and transfer. This is so because it is the users who have the final word in evaluating a new technology. Most potential users of remote sensing technology are simply unmoved by paper-and-pencil evaluation games. They recognize that externally-prepared benefit-cost ratios exclude many of the considerations most important to them. They see impacts on their own decision processes, job security, and organizational behavior being overlooked and obscured behind voluminous but vacuous evaluative reports. The result for the technology developers is often an evaluative "boomerang effect" in which users perform their own subjective assessments and conclude, for various reasons, that fruits from the technology are not worth their price.

By contrast, our notion of a worthwhile exercise in technology assessment is pragmatic: we prefer to learn from the users themselves as they grapple with genuine resource management problems. With this perspective, we can observe the how and why of their decision processes and see where technically-derived information can be of use. It is clear to us that state and local resource managers require more than a few years to adapt a technology as complex as remote sensing to their needs. Adoption of the technology will be an evolutionary process, requiring a multitude of piecemeal adjustments along the way. Contrived calculations and premature evaluations can only serve to divert attention from the more fundamental issues in this process: i.e., how to enable resource managers to make better decisions. We thus feel it is appropriate that those in the business of applying remote sensing concern themselves less with quantifying the value of new information and more with the means for making better use of the technology. Only in this way can we begin to see the technology for what it is really worth.

Chapter 7

SPECIAL STUDIES

Special Study No. 1

CONSIDERATIONS IN THE DEVELOPMENT OF A DECISION-ORIENTED RESOURCE INFORMATION SYSTEM INCORPORATING REMOTELY SENSED DATA IN VENTURA COUNTY, CALIFORNIA

by

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INTRODUCTION

The expanding information requirements of resource management and planning agencies at the international, national, state, regional and local levels have provided considerable impetus to the development of geographic information systems. One example of a local agency which relies on environmental data as input into their decision making processes is the Ventura County Public Works Agency. Although many types of resource data are pertinent to this agriculturally-oriented county, two data sources which offer valuable information and that meet some of the environmental impact assessment requirements are Landsat Multispectral Scanner data and the Defense Mapping Agency (DMA) digital terrain tapes.

As part of its task to provide a guide for the accomplishment of a total resource inventory in a predominately agricultural environment, the Geography Remote Sensing Unit at the University of California at Santa Barbara is currently engaged in a cooperative effort with personnel of the Ventura County Flood Control District in producing a computer compatible tape of the land cover in Ventura County obtained via satellite and merged with limited resolution (63 meter) topographic data.

Legislation such as the National Environmental Policy Act, the California Environmental Quality Act, the State Sub-Division Act, Coastal Zone Act, and the predicted passage of the Agricultural Commission Act, is causing an increase in mandated county data collection requirements with corresponding increases in data acquisition costs and response time. These laws and others have made many traditional data acquisition functions and formats inappropriate or less efficient for meeting legal requirements.

In addition, increased public environmental awareness has in some instances collided with planned provisions for growth. The nature of county level resource management is twofold; 1) growth must be accommodated in harmony with the environment, and 2) planning methods and procedures must be objective, consistent, and comprehensive in order to provide the decision maker with an informed, defensible management tool.

Responsibilities of Resource Management Agencies

Because of the comprehensive nature of the data sets associated with the implementation of many resource management decisions in all environments, the agencies involved have a vital and on-going need for the systematic handling of data. In Ventura County, the Public Works Agency (PWA) is responsible for:

- Flood control
- Water conservation
- Shoreline management
- Hydrological studies
- Geological studies
- Transportation
- Waterworks
- Land development
- Surveying and mapping
- Maintenance
- Sanitation
- Environmental inventories (public projects)

As a recent survey of Public Works information needs was being accumulated, it became obvious that much of the necessary information was applicable to the needs of other county agencies. In particular, the Environmental Resource Agency (ERA) functions as monitor of many natural resource related problems using many of the same or similar data sources as PWA.

The Environmental Resource Angecy is charged with the responsibility for:

- Environmental inventories (private projects)
- Plan and project reviews
- Planning and analysis studies
- Crop census
- Disease detection
- Soil suitability
- Monitoring public health concerns

The ERA is charged with the additional responsibility of processing environmental impact reports as required by the California Environmental Quality Act.

OBJECTIVE

The objective of the research described in this report is to produce a procedural manual for the application of remote sensing to the inventory and management of the"resource complex" in a predominantly agricultural environment. The tasks involved in this undertaking include:

1. The determination of user information requirements for environmental impact assessment.
2. A land cover classification of areas representative of the "resource complex" in Ventura County using remote sensing techniques.
3. The rectification and registration of Landsat data with digital terrain data.
4. An evaluation of the accuracy, reliability, and utility of the Landsat/Digital Terrain Tape information synergism.

STUDY AREA

The areas of interest in this study are defined by the boundaries established on the Oxnard and Matilija quadrangles of the USGS 1:24,000, 7.5' series topographic maps. These areas are particularly representative of Ventura County, with a wide spectrum of features.

Agriculture - the major agricultural area within the county is the Oxnard plain. Crops consist of various labor intensive fruits and vegetables.

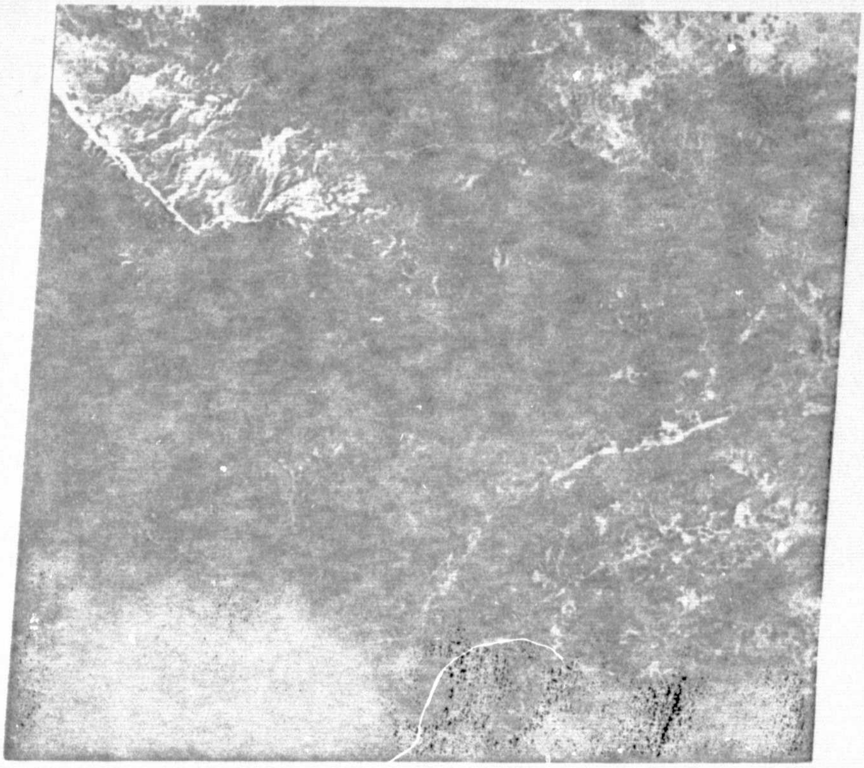
Urban - the major urban features are the cities of Port Hueneme, Oxnard, and Ojai. These areas consist of well developed commercial, industrial and residential areas.

Transportation - the main transportation features are U.S. Highways 1 and 101, the Southern Pacific railroad, the Ventura County Airport, and the Ventura, Channel Islands, and Port Hueneme marinas.

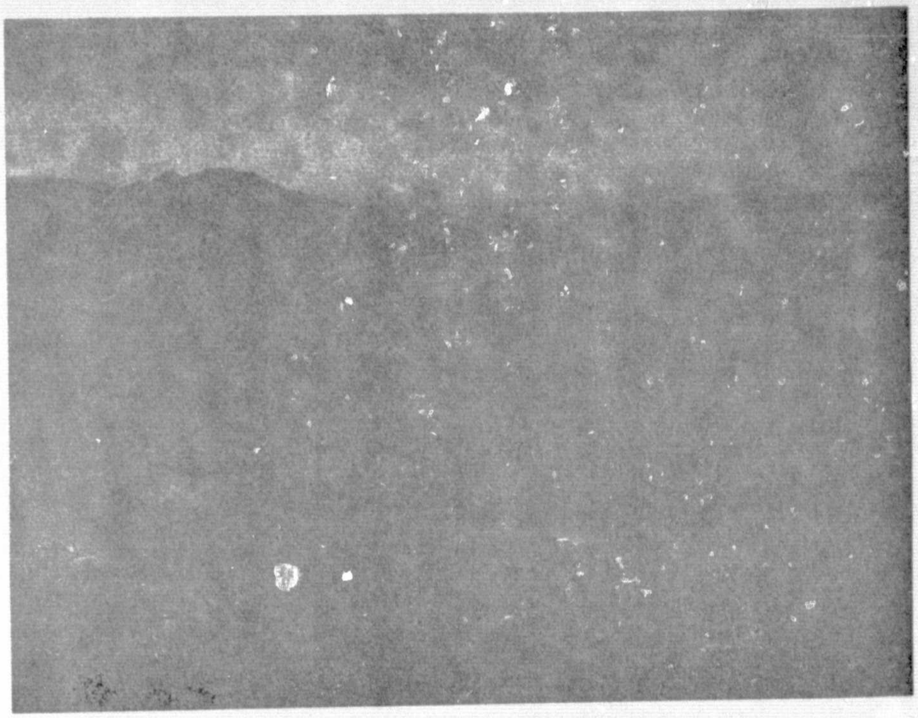
Plant communities - of the eight miles of coast line within the study area, approximately 3.5 miles consist of well developed coastal dunes which are dominated by Coastal strand vegetation. These dune areas are the only remaining extensive dune areas within the county. In addition to the Coastal strand, other plant communities occurring within the study area include Fresh water marsh, Coastal salt marsh, Willow riparian, Hardwood riparian, Coastal sage scrub, Oak woodland, and Chaparral.

Physiography - the predominant physiographic feature is a gently sloping holocene alluvial deposit which comprises the major portion of the study area.

Climate - the climatic regime is of the mediterranean type. Annual temperature extremes are 58°F in January and 82°F in July. Average annual rainfall is 12".

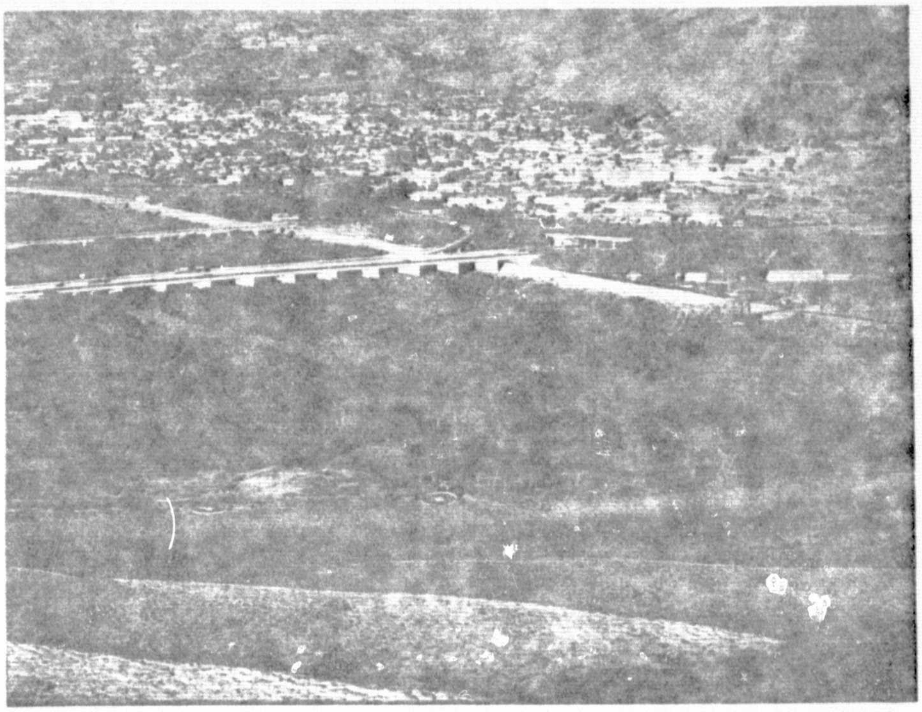


Landsat image of the Ventura County with outline of the Matilija quadrangle (upper) and Oxnard quadrangle (lower).



OBLIQUE VIEW OF OJAI VALLEY

Photo shows mixed agricultural, urban and woodland forest environments at the eastern fringe of the Matilija study area.



OBLIQUE VIEW OF VENTURA RIVER VALLEY

Photo shows sensitive estuarine environment adjacent to the urbanized Ventura area.

INFORMATION COMPONENTS

Remote Sensing Data

The increasing data requirements at every level of government have spurred the examination of a variety of new sources of pertinent data. An extremely useful and versatile data source is supplied through remote sensing. Aerial photographic and image products are "map-like" in their information content and are readily compatible with the graphics orientation of geobase information systems.

Remotely sensed data is applicable to relatively small, site specific resource inventories as well as to large, countywide or statewide resource surveys and can be analyzed for a variety of physical data. It should be possible to provide a quick, accurate means of mapping the vegetation resources within the sudy area by correlating reflectance data obtained from the Landsat system with data about the vegetation obtained from ground and photo sampling. The combination of remote sensing, digital terrain data, and other resource related data can result in a powerful and synergistic data set.

Defense Mapping Agency Topographic Center (DMATC) Digital Terrain Tapes

Topographic data has been obtained form a DMATC digital terrain tape supplied by the National Cartographic Information Center (NCIC). The digital terrain tape is a computer compatible magnetic tape with data recorded by digitizing a USGS 1:250,000 scale topographic map, resulting in elevation values for each 63.5 meter cell (National Cartographic Information Center, 1976).

In addition to elevation values, other terrain information such as slope and aspect can be derived. In essence, a computer program will

compute a gradient vector at each point, with the vector magnitude representing slope angle and the vector direction component indicating aspect (Krebs, et al., 1976).

Geographic Information Systems

Individually both Landsat Multispectral Scanner digital data and digital terrain data would significantly benefit the county's resource management information needs. However, by combining these data sets in common register the resulting synergism offers additional and potentially more useful information to the user. Although procedures for registering Landsat and digital terrain tape data are currently being developed by a number of researchers, (Strahler, 1977; Dozier, 1976; and Krebs et al., 1976), to date no investigation has assessed the use of the data in the management decision process oriented towards the total resource complex.

The development of Geographic Information Systems (GIS) has made it possible to assemble a common data bank in a computer with the capability of storing, retrieving and manipulating large volumes of resource data on a variety of topic categories. This data can be accessed quickly and cost effectively for a variety of applications. In the context of resource management and planning, output products are necessarily graphically oriented to include maps and drawings in conjunction with tabular data.

A geographic-based information system is one which manages spatially-coded data (Dueker, 1972), and should exhibit the following four characteristics (Kohn, 1970):

1. Provide specific point locations, as well as area locations of data.

2. Provide for variable aggregation (sub-setting) of data (i.e. geocoding systems).

3. Provide a method for reproducing spatial arrangements.

4. Ability to interface with mathematical and statistical programs which can be called as needed to aid in the analysis of spatially oriented data.

An image-based information system, such as JPL's IBIS system (Bryant and Zobrist, 1976), utilizes software and digital processing techniques to interface geocoded data sets, digitized thematic maps and remotely sensed data. This approach is extremely amenable for incorporating remote sensing data (such as Landsat), thematic maps, and digital terrain data. In other words, all data is put into image format through digitization or raster scanning and is manipulated through image processing techniques into the context of an information system.

Many states, federal agencies and local jurisdictions have experimented with or implemented computerized geographic information systems. In a study conducted by Washington University (St. Louis, Mo.), over thirty such systems were analyzed to learn something of the functional nature of their operations and to determine what factors might explain the degree of success they have achieved, if any. For eleven systems, thirty-one functional atrributes were examined such as ownership, products available, funding sources, problems encountered and so on. The analysis was based on interviews with system personnel, published reports, and other compendia. Success, as measured by user satisfaction rather than engineering performance, was found to be highest for those systems developed in-house by people familiar with user needs and for systems designed to meet a few needs well. Systems appear to be better received when they can produce map and photographic, as well as computer outputs.

ADDRESSING USER NEEDS

The process of environmental impact assessment requires a large volume of data, of many types at a number of levels of aggregation, (State of California Office of the Secretary for Resources, 1972). The conduct of such an assessment can be seen as analogous to the production of a total resource inventory. It is not difficult to intuitively appreciate the potential that a geographic-based information system holds for meeting the difficult data requirements of the impact assessor. Conceptually, such a system is able to offer the user an array of data of various types, at a number of levels of aggregation, for specific geographical locations dependent upon user requirements. Up to now though, the greatest problem has not been in the development of the information system, but in the finding of interested users and/or in the implementation of the system within their agency (Tomlinson, 1977). Fortunately, such is not the case for this project, where the Ventura County Public Works Agency with support form the County Board of Supervisors and the County Environmental Resource Agency is actively pursuing the development and implementation of an image-based information system. In terms of data development for the system, they have stated a first priority interest in the Landsat and digital terrain data sets.

The following section of our report was prepared by Ventura County personnel as a justification for subsequent investigations into the county-level use of remotely sensed and digital terrain data.

RATIONALE

The rationale behind undertaking the rigorous task of documenting and modeling complex biological interactions in a a geobased context is rooted in the premise that sound resource management policy and environmental impact analysis require a reliable, standardized information system accessible and applicable to a wide range of planning and resource management policy decisions.

To resolve some of these problems, two modifications are currently being considered. The first involves the use of remotely sensed data for vegetative mapping. By using data acquired by multispectral scanning from the Landsat series of satellites, it is possible to obtain good resolution of vegetative types, the ability to assign location to this data, and combine this with a variety of non-remotely sensed information about the same location. The second modification, although intuitively simple, is difficult to apply because it is arbitrary and often subjective. This is the concept of habitat. Habitat in itself represents a refinement over floral/faunal correlation in assigning predictable distribution and occurrence of both floral and fuanal species because it takes into account abiotic physical and structural characteristics as well as the biotic relationships to which organisms address themselves where they occur.

The strength of these two concepts lies in the way that multispectral scanning may be used with other data sources to develop the habitat concept by applying vegetative mapping, terrain data, exposure, and other physical and chemical factors such as geology and soils data. Habitats can be formulated and coded without this treatment, but a multidimensional geobased analysis of faunal distribution promises to have tremendous utility and to be statistically sound. Ground truth will be required for verification of test sites, but this will allow further system refinement.

Landsat offers the opportunity to continuously update the data base and to monitor land use change, both in natural and man-made environments. It is the introduction of this time dimension to accurately model the dynamic nature of biological interactions which lends strength to the analysis of both actual and potential impacts on natural systems. These can be examined cumulatively as well as in long range terms, both locally and in a more comprehensive regional frame. The driving force responsible for this planning and analysis aid is Landsat.

Thomas Wood, Ventura County Flood Control District

The initial County task was to become knowledgeable in flora and fauna inventories, and produce a product that would interface with existing and planned programs, available hardware, and the expertise of per-

sonell in Ventura County. The task of assembling the necessary data base is extensive and must be considered an ongoing task. Data entries are based on relevance and availability of information. Lists of plants and animals have been prepared for every major type of environment in Ventura County. Additional texts have been written on special status wildlife.

Through the conduct of these surveys, it quickly became apparent that many of the problems resource management decision makers are faced with today involve information, its manipulation, and retrieval.

In an effort to secure the time of a County program analyst, justification of a computerized flora and fauna inventory was presented to staff level management and stated that the implementation of such a system would produce a variety of benefits including:

1. Accuracy and consistency improvments,
2. Easier revision of data base,
3. Ease of data manipulation allowing determinations to be made that are not now feasible,
4. Savings in man-hours over present data search techniques,
5. Time saved by supporting personnel, e.g., secretaries, and
6. Ability to expand the data base by incorporating environmental data generated by outside agencies.

These justifications and an explanation of available remote sensing techniques, geo-based and image-based information systems generated an interest in the program and an unofficial commitment of personnel and equipment. Continued involvement of a key punch operator, a program analyst and a growing knowledge of the problems and possibilities of the program led to a revised project that is greater in scope, more sophisticated and readily instituted. In addition the project includes research into other

C.3

applications of the vegetation analysis program such as water conservation, ground water, land use, fire hazard, flood control studies, and soil erosion.

The goals of the original project will likely be met in a shorter time than had been hoped for through the involvement of greater staff support. This involvement has changed the focus of the project from a learning experience to user oriented applications research in remote sensing and experimental usage of remotely sensed data at the County level for environmental resource management (see Appendix 1). Important changes in the project are:

1. A team oriented approach.
2. Division of tasks according to expertise.
3. Planned independence of the Ventura County Public Works Agency from the UCSB Geography Remote Sensing Unit in image processing.
4. Involvement of outside agencies, such as California Fish and Game, U.S. Forest Service, Department of Interior, Fish and Wildlife Service, etc.

Description of the Developing County System

DORIS is an acronym for Decision Oriented Resource Information System. The name was carefully chosen to express the intent of the program designers. DORIS addresses many resource-related problems as it facilitates storage of large amounts of data that can be easily manipulated and retrieved in a cost effective format that allows decision makers to address resource issues in a timely, informed manner. The system has been termed "Decision Oriented" because it is being designed to allow county level resource managers the ability to interactively assess and interrogate data from the system, so that time and cost efficient policy decisions result.

DORIS will initially manipulate spectrally derived land cover data from Landsat, terrain data from digital terrain tapes, and natural resource data from field surveys. These merged and overlayed data sets offer synergistic data for specific information needs of the County's Public Works Agency. Ultimately, a wide variety of data sets will be incorporated into the system. This will be accomplished in response to user data needs as ascertained by a survey of the County's data requirements.

Data Categories

In order to supply the necessary information to the many potential users of DORIS, it will be necessary to acquire a considerable amount of data from a wide vareity of sources. For the sake of convenience, data can be roughly grouped into four categories: (1) cultural, (2) physical, (3) biological, and (4) remotely sensed data.

Cultural data will in many cases be supplied by the user for incorporation into the DORIS data banks, although supplemental information will necessarily be acquired form other sources. As an example, Dime files, general plan maps and archaeological data will originate from the appropriate county and city planning departments and sections. This information will be input (to the DORIS disk) via the board digitizer or fed directly from computer compatible tapes (CCT) via telecommunications link.

Physical data will originate primarily from USGS base maps, DMA digital terrain tapes, U.S. Soil Conservation surveys, California Department of Mines and Geology surveys, and compiled meteorological information

from the U.S. Weather Bureau. CCT information will be fed into the DORIS disk via the telecommunications link, while other graphical and tabular data will be input via the digitizer board or computer card, whichever is appropriate.

Comprehensive *biological data* such as specific flora and fauna information will be input to the DORIS disk through the board digitizer (graphics) and on computer cards.

Remotely sensed data will be rectified, classified, and input into the DORIS disk via a telecommunications link between GRSU and the DORIS center.

Data Interrogation and Analysis

Even with properly rectified and registered data sets, the combined data is not useful information unless it can be accessed and displayed. To accomplish this, data interrogation software must be developed, so that the appropriate information for a particular area is accessible. The actual delimitation of the locations for which there is an information need, (e.g. flood control districts, biological habitat zones, etc.), will be determined by the appropriate planner or resource manager.

The final data output essentially will be a geocoded, multilevel data set containing classified land cover, elevation, slope, and aspect information. Output formats will vary according to the information requirements of a particular user agency.

Past efforts by others in information systems of various types have often led to systems that though technically efficient, are oriented towards hardware and software efficiency not designed primarily for ease

of use by unsophisticated users. Such ease and frequency of use are essential if the users are to become familiar enough with the system to be comfortable in using them in the decision making process. Given the above considerations, the Ventura system has been designed for valid and continuing use in the decision making process in as many circumstances as appropriate. The principal data bank will be stored on equipment maintained by the Ventura County Flood Control District (VCFCD). It is planned that as soon as relatively low cost computer terminals are placed at locations convenient to individual agencies, data sets particular to each agency's needs will be provided.

The master data set and any individualized data sets will be updated as required. This updating will be done upon request, or when such updating is determined by the lead agency to be valuable. The lead agency will also assist other County agnecies in locating or developing computer models with specific applications that may use the data contained in the DORIS files.

TECHNICAL SUPPORT, EDUCATION, AND TRAINING

The University of California at Santa Barbara is responsible for providing technical support to County staff. UCSB will coordinate with the DORIS program development team by aiding in the development of basic software, securing necessary base data, and providing technological services in the areas of cartography and remote sensing.

GRSU is currently developing its software capabilities to implement a variety of image processing programs. Some of these include:

- LARSYS (Laboratory for Applications of Remote Sensing-Purdue University) - a statistical image processing package for the computer-assisted classification of remotely sensed digital data.

- DIRS (Digital Image Rectification System-Goddard Space Flight Center) - an image processing system for the rectification and geographical registration of remotely sensing digital data.

- VICAR (Video Image Communication and Retrieval-Jet Propulsion Laboratory) - a system for the manipulation and enhancement of digital data.

- IBIS (Image Based Information System-Jet Propulsion Laboratory) - a system for manipulation, interrogation, and geocoding of digital data in cell and ploygon format.

These software packages facilitate the efficient transfer of both map and remotely sensed digital data into compatible sets for registration and interrogation. The present system requires technical support and the use of the UCSB Computer Center and Computer Systems Laboratory.

Towards the goal of Ventura County independence from the Geography Remote Sensing Unit's image processing capabilities, a GRSU staff member has been assigned the responsibility for identifying educational needs of Ventura County technical staff and non-technical persons and conducting user training and education programs. He will coordinate with the DORIS Program Development Team by providing user need information and receiving requests for user training.

An exchange of ideas, leading to education and understanding, is an important component of the implementation of DORIS. The personnel involved in this program have the knowledge, desire and ability to accomplish an effective education program for both county and university personnel. Education is required not only of Ventura County personnel in a broad range of basic geographic information systems and remote sensing concepts

and applications, but also of University personnel in the County level data needs and system design priorities. The educational phase of DORIS implementation is presently planned to take two forms: (1) formal classroom instruction, and (2) information workshops and seminars. Emphasis will be placed on the latter of the two, although both types may run concurrently. Formal classroom type lectures are required, as there is a certain body of theory and application constructs which are best presented in this setting. Such course work will be kept to a minimum and informal seminars and workshops will be encouraged. The best way to learn about geographic information systems and remote sensing is by working with the data and problems in a highly interactive environment. For the purposes of this project, formal course work could be arranged through the extended University and conducted through the University of California's Office of Area Representatives. It is anticipated that such courses could also carry university credit. Informal workshops and seminars could be provided in a similar fashion or be held with county departments or other units on an ad hoc basis.

Another responsibility of the GRSU will be to utilize merged digital map and remote sensing data for applications projects. The Geography Remote Sensing Unit is interested in the potential uses of digital map data, combined with remotely sensed data through image processing techniques.

This new and appealing idea of merging remote sensing and terrain data into the context of an information system is certainly not without its shortcomings. Becasue of this, an in-depth look at the accuracy

and reliability of the data from acquisition to output, will be required. This will be accomplished both through a theoretical discussion of the assumptions and decisions concerned with the attributes of the data throughout its manipulation, and through systematic checks with conventionally acquired ground truth data.

ADDITIONAL CONSIDERATIONS OF A USER DEVELOPED SYSTEM

County/State Interactions

The development of state geobased information systems has been retarded due in part to problems other than the technology involved. Many of these problems could be solved or at lease substantially reduced by state-county cooperation during the critical stage of system design. More specifically, a statewide system integrally designed to be upward compatible with county level systems would have the following merits:

- System definition and necessary modifications could begin at the county level with smaller data sets and correspondingly lower initial data acquisition, operation, and update costs. The results of county studies would be easier to confirm and there would be less area to ground truth. County level participation would provide local expertise (for classification and ground truth) which would be difficult to duplicate at the state level. County personnel are better prepared to do accurate classificaiton in finer detail. In addition, assignment of confidence levels in statistical manipulations of the data can more easily be determined by county resource and planning personnel due to their more intimate knowledge of the date set and its utilizations.

- Within a single county there are fewer autonomous agencies to deal with than at the state level so procuring agency support and cooperation would therefore be an easier task.

- Although the initial set of user groups would be more limited, the potential user community for geobased information systems is much broader at the county level. And in addition to traditional resource management and planning activities, a county level information system can be applied to functional "public works" projects that can provide some measure of cost-effectiveness and utility.

Upward compatibility would allow many statewide information needs to be satisfied by aggregation of county data. In contrast, top-down designing runs the risk of alienating potential users through the use of incompatible formats and classification schemes that may not be easily disaggregated to meet county level needs. Early establishment of compatible system features (such as the hierarchical classification scheme proposed by Anderson in United States Geological Survey Professional Paper 964) could avoid these potential problems.

AN INFORMATION SYSTEMS APPROACH TO INVENTORYING THE TOTAL RESOURCE COMPLEX

Information requirements of resource management agencies at the international, national, state, regional and local levels continue to expand. To effectively inventory the total resource complex, resource managers are faced with the need to store, update, and access environmental data in an accurate and efficient manner. The approach taken by this research effort, as an attempt to offer solutions to these resource management needs, is:

1. Conduct a survey of information requirements of county level resource managers.

2. Derive a land cover classification of the two topographic quad study areas from geometrically rectified Landsat/MSS data.

3. Merge the classified study area data set, with terrain data elevation, slope, and aspect) from a Defense Mapping (DMA) digital terrain tape, in the context of an image-based information system.

4. Determine habit zones of various flora and fauna by interrogating the merged land cover and terrain data sets in conjunction with pre-determined biological habitat charactersitics, i.e. vegetation/elevation/aspect.

The general approach as outlined above will seek to implement a digital information storage system that utilizes remote sensing inputs, for resource managers at the county level. Each of the above tasks are described in greater detail in the following pages.

Survey of County Level Resource Management Information Needs

The operational downfall of many goegraphic information systems in the past has been the result of a failure to meet the needs of the intended user. All too often packaged systems have been purchased and implemented, with little consideration of what the user agency requires. Ideally an information system should be custom designed to meet user requirements. But even if an interested agency purchases a marketed system, the designers must consider the characteristic elements of a user's information needs such as resolution, timeliness and formats.

The initial step in our approach has been to request from the Ventura County Public Works Agency their highest priority information requirements. From the list of requirements an assessment was made as to which categorical needs could be met by merging remote sensing data with another data type in the framework of a demonstration project. The highest priority requirements as determined by those agency members with which most communication were made were involved with determining land cover and terrain. A secondary interest of crop identification in the Oxnard Plain agricultural region was also stated, and chosen to be a secondary focus of the research effort.

The Ventura County Board of Supervisors are currently applying for financial aid from the California State Office of Planning and Research (OPR) to conduct an in-depth survey of the information requirements of all county agencies involved in resource management activities. The survey will be conducted with a careful minimization of biasness by members of the Ventura County Public Works Agency and student interns from UCSB. The survey will seek to determine categorical, spatial and temporal

resolution, and output data format information requirements for each division within all resource-related agencies. GRSU researchers will then determine the optimal data source (including remote sensing) as well as how the data is to be incorporated into the information system. Ventura County personnel will make the final decision on priorities for implementation of each data type.

<u>Derive Land Cover Classification from Landsat/MSS Data</u>

As the two high priority information requirements involved the determination of surface cover types at a farily coarse spatial resolution level, it was decided upon to use Landsat multispectral data to derive this information. The study areas chosen to make the analysis are the areas represented by two 7.5 minute topographic quad sheets. The flora and fauna habitat study area is represented by the Matilija Quadrangle and a predomoniately agricultural area by the Oxnard Quadrangle. Land cover classification and other data sets will be merged on a quad-by-quad basis. The Ventura County agencies are planning to develop DORIS so that the 7.5 minute quad is the working storage base.

A digital approach is being utilized and will thus be the scope of analysis in this section and in the Procedural Manual that follows. Consideration of manual remote sensing derived classification will not be discussed here. Readers are referred to references that discuss the manual vs. digital approaches to Landsat derived classification.

The geometric correction of the raw Landsat data is best accomplished prior to classification so that the scene is as close to orthometric as possible. This becomes necessary when developing a geographic-based

information system, as data values must represent their true geographic location. Rectification has been achieved through a two-dimensional least squares fit technique, as part of the DIRS image processing software package. This method requires the selection of accurate ground control points from the Landsat scene (Goddard Space Flight Center, 1976).

Statistical techniques in the digital machine processing of Landsat/MSS data for land cover classification have been the focus of a great deal of research in the past ten years (Anuta and MacDonald, 1971; Su, 1972; Steiner, 1972). The general progression of processing steps are as follows (Lintz and Simonett, 1976):

a. Determination of class categories

b. Feature extraction

c. Pixel classificaiton

d. Output of classification results

Statistical approaches to the classification vary from supervised to non-supervised and parameter to non-parameter. Supervised classification involves the selection of training fields for each class, where the feature extraction phase simply derives class statistics (mean, standard deviation, covariance matrices) as a model for subsequent classificaiton. Non-supervised classification involves the grouping of pixels into classes according to their relative proximity in feature space. Classification is then based on the statistical feature extraction of the "clustered" groups. Parametric and non-parametric approaches differ on the assumption of a gausian distribution of spectral values, and thus go about a different means of deriving classification statistics.

A supervised, parametric approach is being used to classify land cover in the Ventura Study areas. This method was decided upon after considering the time and costs associated with the varying approaches, and the availability of in-house processing software and literature pertinent to the subject. The software used to derive the classification is LARSYS, created at the Laboratory of Applications Remote Sensing (LARS) at Purdue University. The actual classification algorithm uses a maximum-likelihood rule.

Th classification of the Matilija Quad study area for flora and fuana habit assessments, is based primarily on natural vegetation cover classes. These classes are of a level significant to the general vegetative class scheme associated with the habitat zones. They are:

- Coastal sage scrub
- Chaparral
- Oak Woodland
- Grass Lands
- Non-Vegetative (Barren and Urban)
- Fresh Water
- Agriculture (crop types for the Oxnard study area)

Merge Land Cover and Terrain Data Sets

To explore the synergistic charactersitics of merged data sets in an image-based information system context, the Landsat derived land cover data is being registered with the terrain data of the DMA digital terrain tape. This merged geocoded data set should provide the information necessary to determine the flora and fauna habitat zones required by Ventura County resource managers.

Registration is achieved by finding ground control or tie points, relating Landsat pixels and terrain grid cells that represent the same geographic location. This is achieved digitally through a computer algorithm, after the selection of tie points. Upon registration, the stacked data sets become four levels of an digital image-based information system. These levels are:

1. Land cover
2. Elevation
3. Slope
4. Aspect

Levels 3 and 4 are calculated by simple software routines from the raw elevation values of the terrain tape. This is discussed further in the Procedural Manual that follows. By referencing the digital values to a geographic coordinate system, the data sets become geocoded.

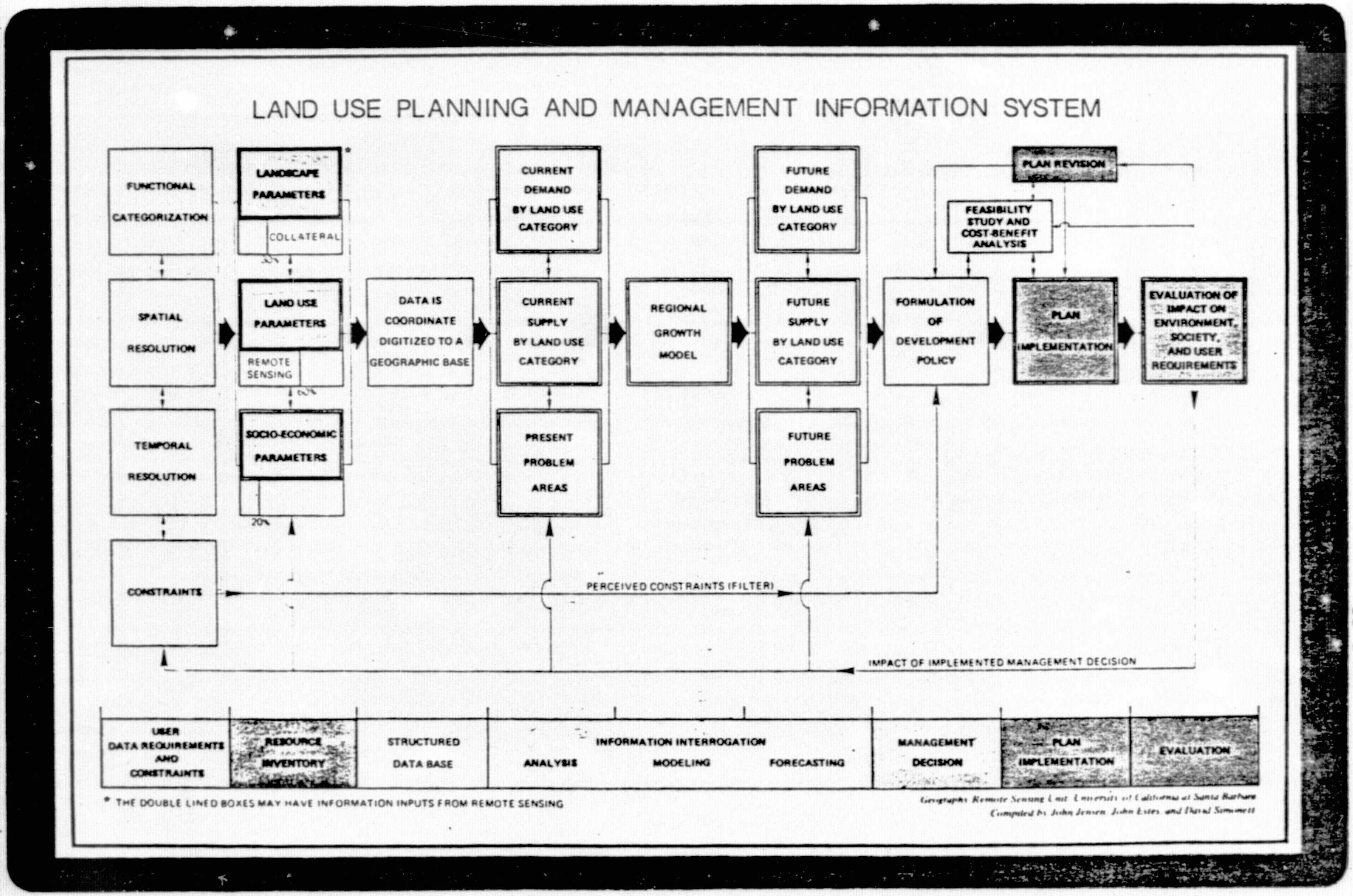
Determining Habitat Zones by Interrogating the Registered Data Sets

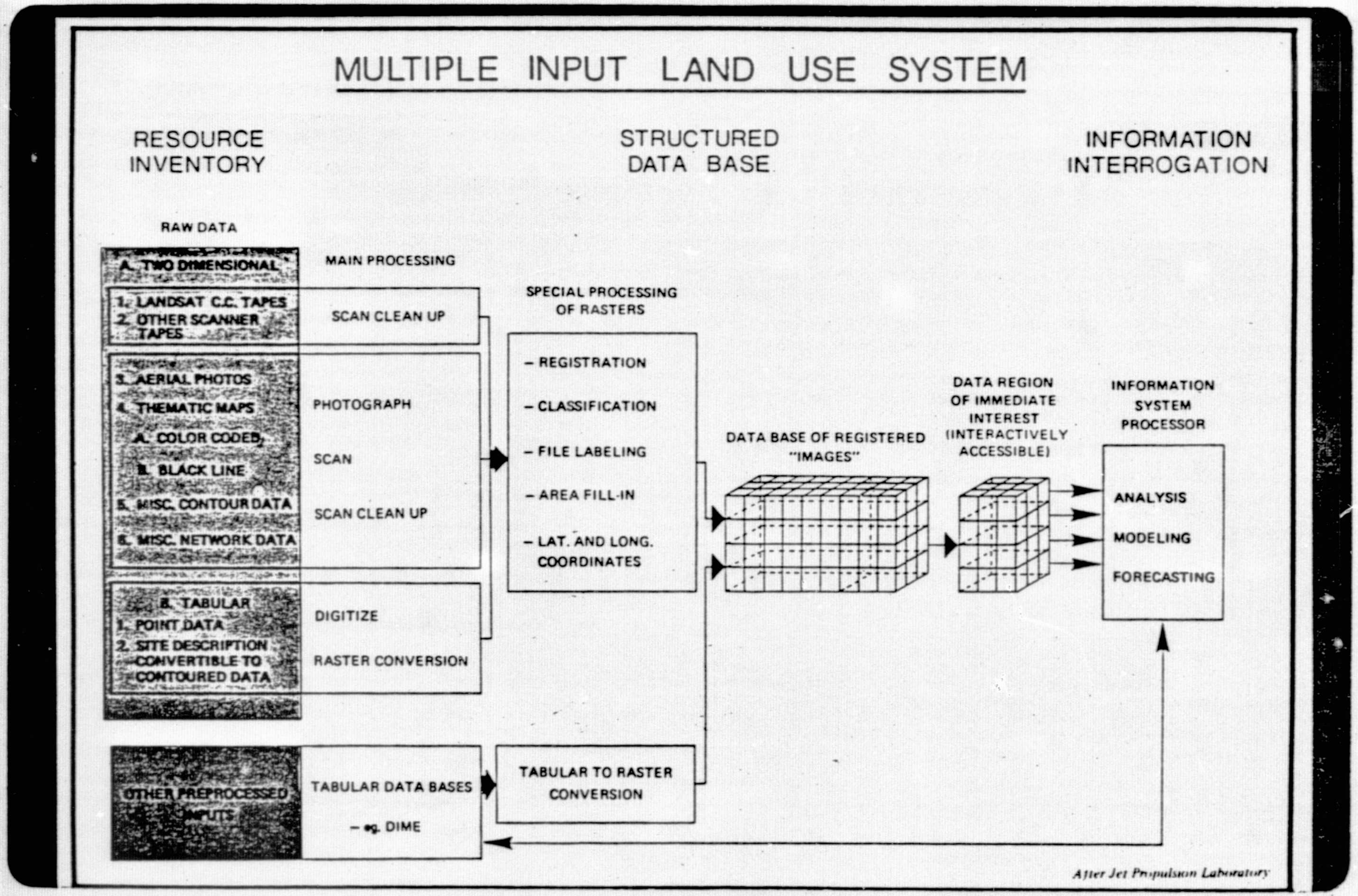
The interrogation of registered, image-based data sets by extracting data for pertinent locations, requires farily sophisticated information system's software. To utilize this data, one must be able to access any point (grid cell), line (chain of grid cells) or polygon area (grid area within a connected chain of grid cells). An image-based system is based on the raster grid as the smallest data storage cell. Thus, if data is needed for a polygon delineated area, a polygon to grid transformation is necessary.

The determination of potential habitat zones will be derived from certain land cover and terrain information criteria. This is based on natural history research conducted by Ventura County flora and fauna experts.

By inputting the various ranges of land cover and terrain conditions associated with a flora or fauna type of interest, it is possible to: 1) determine the number of cells meeting such criterion, which can then be associated with an area measure; and 2) produce a map of potential habitat zones.

The point, line, or polygon accession software will allow the interrogation noted above to be made for locations contained within or on several quad sized data bases. The development of these software capabilities are currently being jointly undertaken by programmers at Ventura County and GRSU, so that they are operational within the time frame of this grant. Futher DORIS development will implement the IBIS (Image-Based Information System) of Jet Propulsion Laboratories, Cal Tech. IBIS will allow these and other useful data interrogation capabilities.


LAND USE PLANNING AND MANAGEMENT INFORMATION SYSTEM
FUNCTIONAL CATEGORIZATION
SPATIAL RESOLUTION
TEMPORAL RESOLUTION
CONSTRAINTS
LANDSCAPE PARAMETERS
COLLATERAL
LAND USE PARAMETERS
REMOTE SENSING
60%
SOCIO-ECONOMIC PARAMETERS
20%
DATA IS COORDINATE DIGITIZED TO A GEOGRAPHIC BASE
CURRENT DEMAND BY LAND USE CATEGORY
CURRENT SUPPLY BY LAND USE CATEGORY
PRESENT PROBLEM AREAS
REGIONAL GROWTH MODEL
FUTURE DEMAND BY LAND USE CATEGORY
FUTURE SUPPLY BY LAND USE CATEGORY
FUTURE PROBLEM AREAS
FORMULATION OF DEVELOPMENT POLICY
PLAN REVISION
FEASIBILITY STUDY AND COST-BENEFIT ANALYSIS
PLAN IMPLEMENTATION
EVALUATION OF IMPACT ON ENVIRONMENT, SOCIETY, AND USER REQUIREMENTS
PERCEIVED CONSTRAINTS (FILTER)
IMPACT OF IMPLEMENTED MANAGEMENT DECISION
USER DATA REQUIREMENTS AND CONSTRAINTS
RESOURCE INVENTORY
STRUCTURED DATA BASE
INFORMATION INTERROGATION
ANALYSIS
MODELING
FORECASTING
MANAGEMENT DECISION
PLAN IMPLEMENTATION
EVALUATION
* THE DOUBLE LINED BOXES MAY HAVE INFORMATION INPUTS FROM REMOTE SENSING
Geography Remote Sensing Unit, University of California at Santa Barbara
Compiled by John Jensen, John Estes and David Simonett


MULTIPLE INPUT LAND USE SYSTEM
RESOURCE INVENTORY
STRUCTURED DATA BASE
INFORMATION INTERROGATION
RAW DATA
A. TWO DIMENSIONAL
MAIN PROCESSING
1. LANDSAT C.C. TAPES
2. OTHER SCANNER TAPES
SCAN CLEAN UP
SPECIAL PROCESSING OF RASTERS
3. AERIAL PHOTOS
4. THEMATIC MAPS
A. COLOR CODED,
B. BLACK LINE
5. MISC. CONTOUR DATA
6. MISC. NETWORK DATA
PHOTOGRAPH
SCAN
SCAN CLEAN UP
– REGISTRATION
– CLASSIFICATION
– FILE LABELING
– AREA FILL-IN
– LAT. AND LONG. COORDINATES
DATA BASE OF REGISTERED "IMAGES"
DATA REGION OF IMMEDIATE INTEREST (INTERACTIVELY ACCESSIBLE)
INFORMATION SYSTEM PROCESSOR
ANALYSIS
MODELING
FORECASTING
B. TABULAR
1. POINT DATA
2. SITE DESCRIPTION CONVERTIBLE TO CONTOURED DATA
DIGITIZE
RASTER CONVERSION
OTHER PREPROCESSED INPUTS
TABULAR DATA BASES
– eg. DIME
TABULAR TO RASTER CONVERSION
After Jet Propulsion Laboratory

By inputting the various ranges of land cover and terrain conditions associated with a flora or fauna type of interest, it is possible to: 1) determine the number of cells meeting such criteria, which can then be associated with an area measure; and 2) produce a map of potential habitat zones.

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SUMMARY AND CONCLUSIONS

In this report a systematic discussion is given of the various considerations that are involved in developing a resource information system, based on remote sensing, that will facilitate the decision-making process as it is praticed by resource managers. Three primary information components for such a system are considered: 1) Remote Sensing Data 2) DMATC Digital Terrain Tapes; and 3) Geographical Information Systems. It is emphasized, with the aid of specific examples, that the satisfying of user needs must be given highest priority, both in the development of data categories and in the formulation of techniques for data interrogation and analysis. The study concludes with a detailing of additional factors that must be considered when developing a user-oriented resource information system. Reference to Chapter 4 of the present Progress Report will reveal how many of these factors and considerations can be systematically treated by the following of successive steps as set forth in a Procedural Manual.

SPECIAL STUDY NO. 2

REMOTE SENSING AS A DEMONSTRATION OF APPLIED PHYSICS

Robert N. Colwell

Note: This is a somewhat modified version of a paper which the author is to present at the forthcoming annual national meeting of the American Physical Society. It is based largely on work performed under the present NASA grant. An abbreviated form of this paper is to be employed by remote sensing training specialists at the NASA Ames Research Center in future training programs conducted by that center under NASA's Western Regional Applications Program. Also the paper has been accepted for publication in a magazine of international circulation known as THE PHYSICS TEACHER. It is believed that all of these measures can further NASA's objective of achieving the transfer and acceptance of remote sensing technology.

REMOTE SENSING AS A DEMONSTRATION OF APPLIED PHYSICS

by

Robert N. Colwell

The basic science known as "physics" is concerned primarily with matter and energy relationships. So is the applied science known as "remote sensing". The primary purpose of this paper is to consider various ways in which the basic principles of physics are finding practical application in the fast-growing field of remote sensing.

As presently understood, the term "remote sensing" pertains primarily to the acquiring of information about features on the surface of the earth from an analysis of data obtained through the use of cameras or other sensing devices that are mounted in an aircraft or spacecraft as it overflies the area of interest. The primary features that are sensed usually are the earth's natural resources, including its timber, forage, agricultural crops, soils, water, minerals, fish, and wildlife. In most instances the property of these features that is being sensed is the amount of energy that is being radiated from them in each of several parts of the electro-magnetic spectrum. The specific purpose of such sensing ordinarily is to inventory and monitor these resources so that the resource manager will know at all times how much of each kind of resource is present in each portion of the area for which he has management responsibility. Given such information he will be able to manage the resources more intelligently. If the objectives of remote sensing are to be realized, those engaged in this field must adequately understand and intelligently apply a great many basic principles of physics.

Experience has shown that the field of remote sensing, dealing as it does with both the conquest of space and the monitoring of resources and environmental conditions on earth, has great popular appeal. The emphasis given in this paper to remote sensing as a demonstration of applied physics should make it of particular interest to both the teachers of physics and their students. In fact, such material constitutes one of the better answers for physics teachers to give to those commendably demanding students who are inclined to ask, at the

end of each classroom session, "So what?"

Because of the fact that certain basic principles of physics need to be applied both in the acquisition of modern-day remote sensing data and in the subsequent analysis of such data, my paper deals successively with (1) Remote Sensing Platforms; (2) Remote Sensing Devices, (i.e., the various types of cameras and other sensors); (3) the Analysis of Remote Sensing Data by Humans; and (4) the Analysis of Remote Sensing Data by Machines.

REMOTE SENSING PLATFORMS

"Platforms", in the jargon of remote sensing scientists, are the various kinds of vehicles on which remote sensing devices are mounted for transport over the areas that are to be remotely sensed. There are three main types of platforms: (1) lighter-than-air craft; (2) heavier-than-air craft; and (3) spacecraft. There is a marked difference in the principles of physics that primarily govern the ability of these types of craft to lift their remote sensors and transport them over the surface of the earth. Specifically, lighter-than-air craft, such as those seen in the top part of Figure 1, exploit the principle that, in a gaseous medium (air), an object such as a balloon or dirigible can be buoyed up if its density is less than that of the surrounding air; (2) heavier-than-air craft, such as those seen in the middle part of Figure 1, exploit the principle that fluids or gasses, when in rapid motion (as when travelling over the curved upper surface of an air foil (wing) exert less lateral pressure than when in less rapid motion (as when travelling over the air foil's less curved lower surface); consequently if forward motion in imparted to the aircraft by means of either propeller blades or jet engines, the aircraft's wings will provide the necessary lift; and (3) spacecraft, such as those seen in the bottom part of Figure 1, ordinarily are wingless, and consequently exploit the physical principles of rocketry to achieve earth orbit.

As launch time for a spacecraft approaches, its rocket engine shoots a jet of gas out of its tail cone. Since for every action there must be an equal and opposite reaction (as decreed by Newton's Third Law of Motion) the spacecraft is slowly lifted off its launching pad, exactly offsetting

the force generated by the jet of gas that is racing in the opposite direction. For as long as the rocket engine continues to fire, the rocket climbs faster and faster, its acceleration being in conformity with Newton's Second Law of Motion which asserts that "the change of motion is proportional to the motive force impressed and is made in the direction of the straight line to which that force is imposed". Once the fuel in the rocket engine has been consumed the spacecraft behaves in conformity with Newton's First Law of Motion in that it continues its motion in a straight line. But there is a caveat to this law (just as there is to many another law these days) specifying ". . .unless it is compelled to change that state by a force impressed upon it." In this instance there is, indeed, an additional force impressed upon the spacecraft, namely the Earth's gravitational pull. Consequently, even as the rocket continues to rise, because of the fact that its rocket engine is providing no more thrust it slows down and curves in conformity with Newton's Law of Gravity which asserts that each particle of matter attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

At this point in the flight of the spacecraft a sort of "tug-of-war" that has been going on ever since lift-off reaches a critical stage. For if the thrust of the rocket engine has been able to accelerate the spacecraft to its "escape velocity", then the craft merely shrugs off the earth's gravitational pull and proceeds on a flight that takes it into deep outer space. Two other results are possible, however: (1) If the rocket engine imparted a significantly smaller velocity, the spacecraft will soon fall back to earth under the influence of the earth's gravitational pull; and (2) If the rocket engine imparted a certain intermediate velocity the spacecraft will have an escaping tendency that is exactly offset by its tendency to fall back to earth under the force of gravity. If and when that balance is achieved, the spacecraft begins to orbit the earth instead of either escaping from it or falling back into it. Theoretically it would be

possible for the spacecraft to orbit the earth indefinitely were it not for still another force acting upon it, namely the drag exerted by the upper atmosphere. As a result of such drag, the velocity of the spacecraft gradually decreases and the orbit decays. The more its orbit decays, the denser the atmosphere that the spacecraft encounters. Hence the amount of drag becomes progressively greater. This "drag factor" is, of course, in conformity with still other basic laws of physics, namely those pertaining specifically to friction.

Since all of the components that relate to a spacecraft's motion, including the several that we have just discussed, can be relied upon to conform to known physical laws, scientists and engineers who are sufficiently knowledgeable about the physics of motion are able to design and build rocket engines and guidance systems that can be counted on to insert a spacecraft, complete with its remote sensing payload, into any desired orbital path. Forthermore, they can either keep it there for a prolonged period of time or modify its orbit as desired through the periodic use of small "booster" jets that remain on board the spacecraft throughout its flight.

With respect to specific types of space platforms for use in remote sensing, there are two which effectively illustrate man's ingenuity and accomplishment - those that are geo-synchronous and those that are sun-synchronous.

A prime example of a remote sensing platform which is geo-synchronous is a weather satellite. The daily "time-lapse" photographs that are acquired by such a satellite of our nation's changing cloud-pattern are familiar to all of us who watch television programs that cover the news of the day, including the weather. A satellite of this type is called "geo-synchronous" because its angular velocity is the same as that of a point on the earth's surface. Consequently as the satellite circles the earth, in equatorial orbit and from west to east at an orbital altitude of about 23,000 miles, it continuously hovers over the same point (or nearly the same point) on the surface of the earth. For this reason it is quite properly called not only "geo-synchronous" but also "geo-stationary". The capability that is made possible from such a satellite of acquiring, from almost the same camera station, repetitive time lapse

photographs of the surface of the earth can be of very great practical value in relation to various earth-monitoring activities. See, for example, Figure 2.

A prime example of a remote sensing platform which is in sun-synchronous orbit is the world's first Earth Resources Technology Satellite (originally given the appropriate acronym, ERTS, but now known as "Landsat".) Compared with that of a geo-synchronous satellite, the orbital path of the Landsat remote sensing platform is somewhat more complicated. Flying at an altitude of 570 miles in a nearly polar orbit (inclined about 9° from the polar axis) this remarkable spacecraft circles the earth every 104 minutes. As the earth rotates beneath it, the net effect of having properly programmed the orbital path of the satellite is this: every 18 days each portion of the earth (except portions near the two polar caps), lends itself to being remotely sensed from exactly the same point in space and at essentially the same time of day - about 10:30 a.m. local sun time. It is for the latter reason that the orbit is termed "sun-synchronous". (See, for example Figure 3).

REMOTE SENSING DEVICES

This sections deals with the actual physical processes that are involved in the sensing of objects at a distance through the use of cameras, line scanners, side-looking airborne radar (SLAR) equipment and other remote sensing devices. In most instances energy that is either emitted or reflected from the objects of interest is recorded by the sensors, either in photographic form or in a form that can be readily reconstituted into a photo-like image. If we are to understand the construction and operation of these remote sensing devices we should first have an adequate appreciation of the basic interactions between matter and energy that are at play when remote sensing is being performed. As previously stated, the energy that usually is being remotely sensed is that from one part or another of the electromagnetic spectrum. We can better understand the nature of electromagnatic energy and how such energy can be transmitted in a wave-like motion, if, at the outset, we make an analogy. The analogy is between electromagnetic waves, whose wave-like properties are difficult or impossible to see directly, and ocean waves whose properties are quite easily observed.

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OF POOR QUALITY

Anyone who has observed ocean waves surely has been impressed by their ability to transmit energy from one part of the ocean to another. He also will have developed the correct concepts of (1) wavelength, (the distance from one wave crest to the next); (2) wave velocity, (the speed with which the wave crests advance), and (3) wave frequency, (the number of wave crests passing a given point in a specified period of time). If he has observed carefully, he will have noted that the wave lengths on one day probably are not the same as on another day, and that, even on a given day, there are not only the primary waves, but various secondary waves also, of different wave lengths. Thus, there is a spectrum of wave lengths ranging from quite short ones to very long ones, all of which are simultaneously transmitting energy. Finally, if he has given it the slightest thought, he will have recognized a simple mathematical relationship of the above parameters which he might express in these terms: The wave frequency, f, is directly proportional to the wave velocity, v, and inversely proportional to the wavelength, λ. This relationship can be expressed by the equation: $f = \frac{v}{\lambda} \cdot a$ where a is a constant whose value depends on the units in which the three parameters are expressed.

All of the foregoing concepts are useful in considering characteristics of another spectrum - the electromagnetic spectrum - which classifies (according to wave length or frequency) all energy that moves with the constant velocity of light in a harmonic wave pattern. ("harmonic" implies that the waves are equally and repetitively spaced in time.) It is this spectrum, hereafter referred to as the e-m spectrum, with which we are primarily concerned, as we consider the basic matter and energy relationships which we wish to exploit through remote sensing. Figure 4 shows a graphical representation of both the e-m spectrum and several remote sensing-related factors that are assocaited with it.

Because various classes of features found on the surface of the Earth reflect differing amounts of light at different wavelengths or wavelength intervals, they can be separated and identified by their own characteristic reflectance patterns, or spectral "signatures". For example, as seen in the upper left diagram of Figure 5, vegetation typically reflects more green light than blue or red and is very reflective (bright) in the infrared. Many dry soils, by contrast, reflect less light in the blue and green

than in the red and can vary widely in infrared reflectance depending on the amount of moisture at the soil surface. As further indicated by Figure 5, a very dark substance such as asphalt reflects very little energy throughout the visible and near-infrared spectral regions whereas, throughout these same regions, a nearly white substance such as cement reflects large amounts.

In the top part of Figure 5, one sees not only the reflectance curves actually obtained in one specific test made by the author for four such surfaces, but also the sensitivities of typical panchromatic and infrared black-and-white sensitive films, the transmissivities of representative filters and the light scattering properties of atmospheric haze particles. The tabulation of predicted tone values appearing in the middle part of Figure 5 shows a unique "tone signature" for each of these four surfaces, based on an analysis of the curves appearing in the four diagrams at the top of the figure. As seen in the bottom part of Figure 5, the actual tone values obtained in this test were in complete agreement with these predicted values.

Using the foregoing basic concepts that relate the remote sensing process to certain basic principles of physics, we can now proceed to a useful summary of that process. Keeping in mind that the (a) basic unit of energy throughout the electromagnetic spectrum is known as a "photon"; (b) the smallest particle of an element that can exist either alone or in combination is an atom; and (c) the smallest particle of a multi-atomic substance that can retain the properties of that substance is a molecule.

1. Atomic matter and energy relationships that are involved in the remote sensing process may be summarized as follows:
   a. When an atom absorbs the energy of a colliding photon, an electron in the atom's shell may be shifted to an orbital path of higher energy level; in that event the photon ceases to exist.
   b. When an atom liberates energy, an electron in the atom's shell may be shifted to an orbital path of lower energy level; in that event a photon is generated where none existed before.
   c. The number of "allowed" electron shifts, and their attendant changes in energy, are absolutely characteristic for each atomic species; consequently each atomic species has unique absorption and emission spectra which can be exploited in remote sensing to provide unique tone signatures.

2. Molecular matter and energy relationships that are involved in the remote sensing process may be summarized as follows:

   a. Molecules, like atoms, have definite energy states; energy changes involving the absorption or emission of photons by molecules follow the same basic relationships as in atoms.

   b. Photon effects in molecules may arise from either

      (1) electron shifts in the bonding of atoms of the molecule, producing energy changes in the UV and V;

      (2) vibrations of atoms within the molecule, producing energy changes in the near- and middle-IR;

      (3) changes in the rotational energy of the molecule as a whole, producing energy changes in the IR and microwave regions.

3. In order for a remote sensing system to operate effectively within any specified wavelength range of the electromagnetic spectrum there must be:

   a. an energy source (such as the sun) which will provide photons having the proper energies and hence the proper wavelengths,

   b. a collection of matter (such as a tree or rock) which will interact with photons in this range,

   c. an energy detector (such as a photographic film) which is sensitive to photons in this range.

   d. a propagating medium (such as the atmosphere) between detector and target, which will transmit photons in this range*, and

   e. an energy filter (typically a glass or gelatin filter in the "Wratten" series) which will screen out unwanted photons to which the detector is sensitive, while transmitting the wanted ones.

4. When a photon of any specific energy strikes the boundary of solid matter, a number of interactions are possible; mass and energy are conserved according to basic physical principles, and the energy can either be absorbed, emitted, scattered, or reflected.

5. Absorption, emission, scattering and reflection of electromagnetic energy by any particular kind of matter are selective with regard to wavelength, and are specific for that particular kind of matter, depending primarily upon its atomic and molecular structure. Therefore, we can, in principle, identify any type of feature on the surface of

*or else a void such as that existing in most of the vast expanse that separates the sun from the earth.

the earth by comparing its multiband spectral response, as obtained by remote sensing, with the known spectral responses of all of the types of features that are likely to be encountered within the study area.

6. The atmosphere is a turbid medium whose scattering particles, for the most part, have diameters commensurate with the length of light waves. Light scattering by these particles is inversely proportional to the fourth power of the wavelength of the light, in accordance with Rayleigh's Law and as diagrammed in the upper right corner of Figure 4.
7. In addition, the atmosphere exhibits distinct molecular absorption bands at various points in the electromagnetic spectrum caused by the presence of such molecules as N_2, O_2, O_3, H_2O, CO, and CO_2. The location and intensity of each of these bands are predictable from a knowledge of the matter and energy relationships for each type of molecule present in the atmosphere.
8. In the photographic process, latent image formation in the silver halide crystal takes place in the following distinct steps.
   a. The crystal absorbs a photon, which raises the energy state of an electron in the crystal.
   b. This electron passes from the crystal to a silver sulfide "speck" associated with the crystal.
   c. The electron on the "speck" attracts, and unites with, a silver cation, thus forming an atom of metallic silver.
9. The three-step process of latent image formation is repeated as each additional photon is absorbed, thus causing the "speck" to grow. During film development, reducing agents provide many additional electrons to each silver halide crystal that is associated with an activated "speck", thus reducing all the silver halide in the crystal to opaque metallic silver.

The "amplification" in this process (in relation to the number of photons absorbed) may exceed one billion times, in photographic films of high sensitivity.

Now that most of the basic principles of physics that govern the process of remote sensing have been described, let us briefly consider the major types of cameras and other sensing devices that have been developed in order to exploit these principles. In so doing, let us keep in mind that our primary

interest here is in disclosing any principles of physics (and especially principles in addition to those already discussed) that govern either the construction or the operation of these devices.

There are six types of remote sensing devices which show greatest promise for the inventory of natural resources. These are (a) the conventional aerial camera, (b) the panoramic camera, (c) the multiband camera, (d) the optical mechanical scanner, (e) the side-looking airborne radar device (SLAR), and (f) the gamma ray spectrometer. Let us now briefly describe the construction and operation of these various devices with emphasis on the specific interests of the physicist.

A. The Conventional Aerial Camera

The four basic components of a modern aerial camera are the magazine, drive mechanism, cone and lens. While the first three of these often are engineering marvels, the lens or fourth component is almost invariably the most costly and the most important. This fact alone might seem to justify our giving here a lengthy discourse on physical optics including a very practical discourse on the need for overcoming, in these camera lenses, such problems as chromatic aberration, coma, and curvature of field. But, resisting this temptation and recognizing that we already are quite familiar with conventional cameras, let us progress quickly to a discussion of the other five types and in so doing indicate how such problems are either overcome or minimized by them.

B. The Panoramic Camera

The priniple on which the panoramic camera operates is indicated diagrammatically in Figure 6. With this camera it is possible to photograph a large area in a single exposure at very high resolution (i.e., with a high degree of image sharpness in every part of the photograph). The camera meets a need but creates some special problems. The need results from the fact that it often is desirable to cover large areas with only a few frames of photography. Until recently this necessitated using wide angle camera lenses and flying the photography from high altitudes. In an effort to improve resolution on this high altitude photography, a lens of long focal length sometimes was used, but a lens having both a long focal length and a wide angular field suffers from several types of aberration, especially near the perimeter of the field, so that high resolution photographs usually cannot be obtained with it after all. Consequently, for years it seemed

paradoxical to require both (1) high resolution that could only be provided by a lens having a narrow angular field and a long focal length and (2) wide swath coverage (maximum area coverage per frame), that could only be provided by a lens having a wide angular field and a short focal length. For many purposes, however, this problem has been adequately solved by a panoramic camera which does indeed have a long focal length, and which provides high definition within a narrow angular field. The narrow angular field of the lens is still further restricted in the panoramic camera by a narrow slit in an opaque partition near the focal plane of the camera. The slit is parallel to the camera platform's line of flight. With such a slit, however, one would be able to photograph only a narrow swath of terrain unless the optical train of the camera were to be equipped to "pan" (move from side to side) as the aircraft advances. The optical train of the panoramic camera is designed to make such movements, as diagrammed in Figure 6.

For the panoramic camera to maintain a uniformly clear focus as the optical train moves, the frame of film being exposed must be held in the form of an arc instead of being kept flat, as in a conventional camera. With the film in an arc the photographic scale becomes progressively smaller as the distance of objects on the ground increases to the left and right of the flight path. In some applications the scale problems outweigh the advantage of a panoramic field of view, so that it is preferable to use a conventional camera. There are many image analysts, however, who are beginning to make very effective use of the panoramic camera to obtain with only a limited number of flight lines, ultra high resolution imagery of very wide swaths of terrain.

C. <u>The Multiband Camera</u>

Earlier in this discussion, we emphasized the value of our knowing the <u>multiband</u> spectral response for each type of feature that we wished to identify and, in Figure 2, we gave one practical example of this concept. Numerous other investigations also have shown that far more information can be obtained from a study of remote sensing images taken simultaneously in each of several wavelength bands than is obtainable from those taken in any one band (Colwell, 1961). Realization of this fact has led to the development of a concept known as "multiband spectral

reconnaissance" and also to the development of various multiband cameras for the taking of simultaneous photographs in each of several spectral bands (See, for example, Figure 7). By proper choice of photographic film (in terms of its spectral sensitivity) and filter (in terms of its spectral transmissivity) the limits of each spectral zone within which remote sensing is to be accomplished can be controlled, as necessary, to obtain the maximum amount of the desired information from that zone. Through the use of such equipment, much more information regarding certain objects and conditions, within a natural resource area for example, can be obtained from the composite "tone signature" (i.e., from a study of tonal values on several of these frames) than from a study of tonal values on any one of them.

D. The Optical Mechanical Scanner

In an optical mechanical scanning system, such as that shown in Figure 8, the "collecting optics" is in the form of a mirror, or series of mirrors, rather than a lens. When multiband reconnaissance must include sensing in the thermal infrared region the optical mechanical scanner can provide photo-like images, whereas cameras of the types previously described cannot.

There are at least two reasons why reflective optics rather than refractive optics are used in an optical mechanical scanner, both related to problems of sensing in the thermal infrared part of the spectrum:

1. Relatively few materials can instantaneously transmit energy in any part of the thermal infrared region, and even fewer over the very wide range of wavelengths for which thermal infrared scanning is desired; and
2. Refracting lens systems are unable to sharply focus, in a single focal plane, all radiant energy from a wide spectral band (i.e., one that encompasses a very wide wavelength range, such as the thermal infrared). Both difficulties are overcome through the use of first-surface mirrors as reflecting optics.

An additonal problem prevents the obtaining of thermal infrared imagery with a camera of conventional design. This problem pertains to the recording of images in a photo-like form. Thermal infrared sensitive materials can be produced that are similar to the light-sensitive silver

halides of a photographic film. However, if such materials are made to respond at ambient (environmental) temperatures, how can they be kept from becoming fogged by heat due to gradual exposure, even as they repose, ready for use, inside the infrared camera? Obviously, even the interior of such a camera (the portion facing the film) is continuously emitting thermal energy. Therefore, just as the conventional camera must be a "light-tight box" if it is to prevent light-sensitive film from fogging, so a thermal infrared camera would have to be a "heat-tight box" if it were to prevent heat sensitive film from fogging. In fact, the box would have to be cooled to a temperature approaching absolute zero. Although the required low temperature could be achieved, the weight and volume requirements for the cooling equipment which would maintain this low temperature for such a sizable structure would prohibit its use in most aircraft or spacecraft. Furthermore, at such a low temperature additional problems would be entailed because of brittleness of both the film and certain of the camera components.

The solution which modern science has devised for the problem just described is the optical mechanical scanner diagrammed in Figure 8. This device consists essentially of three parts: (1) the energy collector or scanning mechanism, (2) the detecting mechanism and (3) the recorder.

The design of the energy collector reflects the fact that no satisfactory means has as yet been found (when working with thermal infrared wavelengths) for simultaneously imaging separate elements in a wide angular field, the way a conventional camera does. Instead, it is necessary to focus on one small element at a time, and the size of this small "instantaneous field of view" determines the pictorial resolution.

All of the photons collected by the scanner within its instantaneous field of view are focused on the detector. There they generate an electrical charge. Ordinarily the actual detecting element is nothing more than the tip of an electric wire onto which some thermally sensitive material (e.g., copper-doped germanium) has been attached. Hence it is only this small element that needs to be cooled, (e.g., by jacketing it in a small Dewer flask as indicated in Figure 8). Because sensing is being accomplished in the thermal infrared region, the greater the thermal energy being emitted within the instantaneous field of view the greater the charge or signal that is generated (i.e., the greater the surge of

electrons, escaping from the detector and travelling along the electric wire). This signal is then used to modulate a visible light source such as one "instantaneous element" of a cathode ray tube. The output signal is made to scan the cathode ray tube in the same pattern as the collecting optics scanned the scene beneath the aircraft. The mirror of the collecting optics rotates on an axis that is parallel to the flight line and thus scans a line that is lateral to the flight line. The mirror looks at only one small portion of the terrain at any given instant, and the beam collected illuminates only a correspondingly small spot on the cathode ray tube and on the photographic film placed in front of the tube (Figure 8) at the same instant. The rotating mirror, aided by other elements of the optical train, thus images a swath of terrain across the film. By the time one swath has been painted on the film two events have occurred: (1) the reconnaissance vehicle ("platform") has advanced sufficiently so that one of a series of companion mirrors mounted in other positions on the same rotating shaft begins to look at the next continuous swath of terrain, and (2) the roll of photographic film in the camera that faces the cathode ray tube has advanced sufficiently in its focal plane so that this next swath is painted on the film in proper juxtaposition to the first swath. The density of each portion of the exposed film is in direct proportion to the strength of the infrared signal coming from the corresponding terrain. Hence, as the aircraft advances the film advances and a continuous photo-like image (thermogram) is formed.

E. <u>The Side-Looking Airborne Radar Device (SLAR)</u>

Because of its all-weather, day-and-night capability, and its partial ability even to penetrate the vegetation canopy and sense the terrain beneath, radar equipment is of great interest to those who seek to inventory natural resources by means of remote sensing. However, radar devices operate at much longer wavelengths than any of the equipment previously described. Consequently, difficulties arise in acquiring high resolution imagery with such devices because, as with any diffraction-limited system, the longer the wavelength the poorer the resolution.

Tremendous improvements have been made recently, however, in the quality of radar imagery through the development of a form of SLAR equipment which, as described below, cleverly exploits several basic principles

of physics that are in addition to any that we have previously discussed.

A transmitting antenna in the reconnaissance aircraft sends out a short pulse of microwave energy to one side of the aircraft and thus illuminates the roughly circular lobe (See for example the lobe on which points A and B have been annotated in Figure 9). This lobe corresponds to the instantaneous field of view in a "diffraction limited" radar system.

A receiving antenna mounted in the same aircraft collects energy reflected back from the illuminated terrain. The greater the distance from aircraft to target, the greater the time delay in return of the reflected signal. Through accurate measurement of the time delay, it is possible for this equipment to differentiate returns from various small concentric "rings". Each ring represents the locus of all points within the illuminated circle that are roughly equidistant from the aircraft. Within any ring there is a spot, just opposite the aircraft, that moves along at the same speed as the aircraft. At any given time the distance from the aircraft to all other points on the ring is either increasing or decreasing. Consequently, through the Doppler effect, the microwave energy reflected back to the aircraft from such points is of a different frequency than that which had been transmitted to them by the radar pulse. The radar receiver is designed to accept those wavelengths which are of approximately the same frequency as the initial pulse, but to reject those of significantly different frequencies.

Because of the two discriminating features just described, the only energy accepted by the radar receiver at any given instant is that which satisfies two conditions: (1) it is in the narrow ring within which time delay is such that the energy is at that instant striking the receiving antenna and (2) it is in that particular part of this ring which is directly opposite the aircraft (the area having zero relative velocity with respect to the aircraft and therefore exhibiting no Doppler frequency shift). The combination of these factors effectively provides a "sensing capability" that greatly improves the spatial resolution of the system.

In order to record this accepted energy in photo-like form, two other radar components are used: a cathode ray tube and a roll of photographic film. The strength of the signal determines the brightness of a dot. The

position of this spot on the cathode ray tube changes synchronously with the antenna scan. Thus, for any given scan line, the signal that first returns is that from the inner edge of the illuminated area and is imaged at the bottom of the cathode ray tube. As time goes on, the return signals come from farther and farther away and are directed farther and farther up the scan line on the cathode ray tube. At the time the signal is returning from the farthest point illuminated, the spot on the tube has moved all the way from the bottom to the top. Photographic film which (as in the optical mechanical scanner) is in juxtaposition to the tube is exposed by this means, one line at a time. By the time the next pulse is transmitted, the film has advanced slightly and so has the aircraft. The density of each portion of the exposed film is in proportion to the brightness of radar signals coming from the corresponding spot on the terrain. As the aircraft advances, the film advances and thus a continuous photo-like record of the terrain is produced.

F. The Gamma Ray Spectrometer

This device is designed to exploit the fact that many minerals sought by the geologic prospector emit gamma rays because they are either naturally radioactive or are chemically combined with components which, in turn, are radioactive. When airborne, this device measures incoming gamma radiation primarily from that portion of the earth's surface that is beneath the flight path of the aircraft. It can measure both the total gamma ray output and the spectral output of gamma rays in as many as 400 channels or spectral bands, each of which may contribute to the identifying signature of some radioactive substance. The energy of each gamma ray given up within the detector provides a proportional electrical pulse which is sorted out by a multichannel analyzer to provide radiation spectra.

BASIC PRINCIPLES OF PHYSICS THAT ARE APPLIED IN THE ANALYSIS OF REMOTE SENSING IMAGERY BY HUMANS

This phase of our discussion is facilitated by our first defining the term "image analysis", which is a recent successor to the term "photographic interpretation." Image analysis is the act of examining images for the purpose of identifying objects and judging their significance.

The act of examining images is greatly facilitated if the analyst is provided with good imagery. Two ways of improving image quality are (a) by

improving the "signal-to-noise ratio", and (b) by presenting images to the analyst in full color, rather than in monochromatic shades of grey.

One way of improving the signal-to-noise ratio- a way which in itself exploits several fundamental principles of physics - entails the construction of a single composite photograph from several seemingly identical photographs. The remote sensing device that is commonly used in obtaining the several photographs consists of a "gang" of eight cameras, all of which are operated simultaneously at the time when the aerial or space photographs are being taken. All eight cameras are contained in a single camera mount and suitably bore-sighted. Each is equipped with a good lens and also each uses the same kind of high resolution photographic film and the same type of filter as are employed in the other seven cameras. The filter usually is of the "minus blue" type, and thereby eliminates most of the troublesome scattering of light by atmospheric haze that would tend to cause image blur. It is at this point that we find ourselves indebted to yet another physicist, Rayleigh, for establishing that the scattering of light by atmospheric haze particles is inversely proportional to the fourth power of the wavelength of the light. Consequently by our using a minus blue filter to eliminate the shortest wavelengths to which most films are sensitive we often are able to improve the sharpness of images (of features on the surface of the earth) quite dramatically.

By our using the equipment, techniques, and principles that have just been described, we might expect all eight images to be identical, and so they appear to be when examined only superficially. But in each of the eight images various "noise" problems (e.g., those due to lens aberrations or film graininess) tend to be <u>randomly located</u> throughout the negative, while the real signal (e.g. the image of some feature of interest) tends to be <u>uniformly located</u>. Hence a device known as a "multiple image correlator" has been cleverly devised by our physicist friends. This instrument has eight film holders, one for each photographic negative (or a positive transparency made from it). The optical trains leading from these holders are such that all images are presented simultaneously and in proper register on a viewing screen. Physicists tell us that they can quantitatively express the improvement in image quality (sharpness) that such equipment is likely to provide to the image analyst. Specifically, if "n" is the number of such images that are optically combined by the multiple image correlator

the image quality (sharpness) is likely to be ~~improved~~ by an amount equal to the square root of n. Thus, since the correlator employs eight images one might expect (and in actual practice does, indeed, enjoy) nearly a threefold improvement in image quality.

Physicists also have explained to us the advantages of presenting images to the analyst in full color, rather than in monochromatic shades of grey. They have demonstrated that, even under the most favorable conditions, the average image analyst can perceive no more than about 200 shades of grey on black-and-white photography, whereas he can perceive more than 200,000 different combinations of hue, value and chroma on color photography. In some instances the desired improvement is accomplished to a significant extent through the use of color film, rather than black-and-white film, at the time of photography. But in order to exploit this principle much more fully, physicists have devised and built various closed circuit color television systems which are capable of both "density slicing" and "color coding" when applied to a photograph. Typically, a single, high resolution black-and-white photograph is presented to the television camera. Then, by appropriate manipulation of control knobs, the instrument operator can select for enhancement any desired "density slice" (small range of densities on the original photograph). Through further manipulation of the controls, the image analyst finds that subtle differences in tone that were not perceptible on the original photograph can be electronically "stretched out" to occupy the full grey scale range and thus be made readily discernible. By further manipulation of the controls he then assigns to the color monitor (TV screen) a unique color for each shade of grey that is exhibited on this density-sliced and density-stretched image. Experience has shown that the image analyst, when given a few "ground truth" examples for calibration purposes, i.e., examples that tell him the identity of selected features on the imagery, can relate each color coded image to the corresponding ground feature and thereupon complete his interpretation of the entire scene with remarkable ease and accuracy.

As we complete this brief discourse on the examining of images we find ourselves once again indebted to physicists for demonstrating to us that our task can be made much more productive merely through proper adjustment of the overall intensity of lighting. A person's binocular visual acuity varies

with the pupillary diameter of each eye. This in turn will vary, of course, with the overall lighting intensity of the scene that is being viewed. For most image analysts, the maximum visual acuity is reached when the overall lighting is such as to cause the pupillary diameters of the two eyes to be approximately 4.0 mm.

BASIC PRINCIPLES OF PHYSICS THAT ARE APPLIED IN THE ANALYSIS OF REMOTE SENSING DATA BY MACHINES

As implied in the previous section a large number of identifying characteristics can by employed when the image analyst is a human rather than a machine. The human brain is able to integrate such diverse clues as are provided by the size, shape, tone, texture and topographic site of a feature that is to be identified, as well as those provided by its association with other features. When, however, the image analyst is a machine (i.e., a computer), only one of these characteristics, (tone or brightness) has thus far been found to be useful, simply because it is the only one that is readily and meaningfully quantifiable. Even when this characteristic alone is relied upon, complications usually arise because of problems in variability. To the physicist it might at first seem that this would be a negligible problem in light of our having emphasized in a previous section that those factors governing the tone or brightness of a feature (absorption, emission, scattering and reflectance) are selective with regard to wavelength and specific for each kind of matter, depending upon its atomic and molecular structure. But we must be careful about using the terms "feature" and "matter" interchangeably. The fact is that virtually every feature that we wish to identify is composed of somewhat variable aggregations of matter and hence has variable atomic and molecular composition. Thus for example if we wish, as in a typical instance involving the remote sensing of natural resources, to identify all of the ponderosa pine trees, or sandy loam soils, or polluted water bodies, or rust-infested wheat fields, we find that each of these features exhibits some variability in its aggregations of matter and consequently some variability in its spectral response to radiant energy. Therefore its tone signature, as imaged by remote sensing devices, tends to be somewhat variable.

Much of the research that currently is being done in remote sensing seeks to find those parts of the electromagnetic spectrum within which (a) this variability is minimal for any given type of feature that is to be identified, and (b) at the same time the feature's spectral response is unique. A detailed account of one such effort appears in the previously mentioned article on basic matter and energy relationships (Colwell, et. al., 1963).

Given a better understanding of the basic principles of physics that have been discussed in this paper, remote sensing scientists might eventually develop a highly automatic system, in which an unmanned satellite orbiting the earth would carry multiband sensing equipment together with a highly specialized system of computers. Thus equipped the satellite could, for any particular area, take inventory of the resources and produce a printout that would amount to a resource map of the area. The computer could then use the inventory data in conjunction with preprogrammed factors (such as what ratio of costs to benefits would be likely to result from various resource management practices) and could reach a decision for the optimum management of the resources in the area. The decision would be telemetered to the ground for whatever action seemed necessary.

As a simple example, the satellite's sensors might spot a fire in a large forest. Its computer might then derive information on the location and extent of the fire and could assess such factors as the type and value of the timber, the direction and speed of the wind and the means of access to the fire. On the basis of the assessment the computer would send to the ground a recommendation for combatting the fire (See Figure 10).

Capabilities of this kind need not be limited to emergencies. Many routine housekeeping chores now done manually by the resource manager could be made automatic by electronic command signals. As further suggested in Figure 10, examples might include turning on an irrigation valve when remote sensing shows that a field is becoming too dry and turning off the valve when, a few orbits later, the satellite ascertains that the field has been sufficiently watered.

A satellite of such capabilities may seem now to be a far distant prospect. After a few more years of developing the techniques for remote sensing the prospect may well have become a reality.

DO IT YOURSELF REMOTE SENSING FOR THE PHYSICIST

As we conclude this discourse, let us abruptly turn from some of the most sophisticated applications of physics (as just discussed) to some of the more mundane applications that are well within the reach of all of us.

It often has been the author's experience that both the teachers of physics and their students, on learning of the modern day marvels of remote sensing, have indicated to him that they would welcome the opportunity of becoming personally involved in some remote sensing-related activity, perhaps as a hobby. Too often, however, they have dismissed the idea on the assumption that only those with large financial resources and an abundance of time could enter into this field. This is by no means a valid assumption. To the contrary, the ingenuity of the physicist can lead to quite inexpensive and useful endeavors in all 4 of the aspects dealt with in this paper, viz. those dealing with remote sensing platforms, remote sensing devices, the analysis of remote sensing imagery by humans and the analysis of remote sensing data by machines. All four fields of activity are illustrated in the following example.

A remote sensing enthusiast with adequate understanding of the basic principles of physics found it quite easy to construct the "drone" or "remotely piloted" photographic aircraft that appears in Figure 11 (Sheppard, 1976, 1977). In so doing he used a modified Telemaster model airplane kit which cost him less than $90. He then equipped it with a single cylinder, naptha burning, one horsepower engine at a cost of $80. As indicated by the right photo of Figure 11, he found that this platform, while being remotely controlled, could transport a very useful remote sensing payload. For example, either a 35 mm aerial camera or a uranium prospector's scintillometer could be flown by this aircraft on a low altitude reconnaissance mission at a cruising speed of 60 mph and with an endurance of more than 1 hour, provided that the weight of the payload did not exceed 10 pounds, including the radio receiver and a servo unit. Although the wings of this particular aircraft have a span of 8 feet, they are hinged in the middle and, like the tail assembly, are readily detachable, leaving the 5-foot fuselage as the largest single piece and thereby facilitating transport by automobile. Consequently he was able to drive

with this equipment from one place to another, in each instance selecting a suitable vantage point near the area that he wished to photograph so that, from that spot, he could not only launch the aircraft but also maintain line-of-sight communication with it and control it. He found that, upon arriving at any such vantage point, he could reassemble the aircraft and have it ready for flight in less than 5 minutes. Furthermore, he could control its flight path well enough to cause it to navigate to a distance of two miles or more (so long as he could still see it) prescribed flight lines, all the while acquiring low altitude vertical aerial photographs with the proper overlap for stereoscopic viewing.

As illustrated by Figures 12 through 19, a good many uses already are being made of aerial photographs of the types that can be readily and economically obtained from a remotely piloted vehicle. Some of these photos (Figure 12, e.g.) represent little more than the product of a successfully pursued hobby. Many of them, however, e.g. Figures 13-19, can find very practical application as aids to the inventory and management of natural resources. This is true, for example, when they are used as elements in a multistage sampling scheme, i.e. a scheme in which aerial photos of progressively larger scales are obtained of sub-sample areas which are progressively smaller in size (Langley, 1971; Colwell, 1975). Still others are of value when, perhaps in addition to the above, they are so taken as to provide multiband photography (Figure 13) or multistation photography (Figure 18).

Most of the resulting aerial photographs would normally be subjected to analysis by humans and for this reason rather complete captions have been written to accompany Figures 12 through 19, the better to indicate the nature and meaningfulness of these analyses. In this regard the physics hobbyist should know that most of the image analyses are performed while studying a pair of overlapping photographs 3-dimensionally. This ordinarily would entail viewing them through a rather expensive piece of viewing equipment known as a stereoscope. Since suitable overlapping photos can readily be obtained from the piloted aircraft, many an innovative physicist has risen to the challenge of building his own stereoscope, quite inexpensively and in the following manner: (1) from the local department store, two small (e.g. 2-inch diameter) monocular

lenses are purchased. The lenses should be reasonably well matched in terms of their focal lengths and the degree of magnification which they provide, which preferably should be in the 3X to 4X range. (2) From a piece of stiff cardboard, a binocular spectacle-like frame is carved such that, when the 2 lenses are placed within it, their optical axes will be essentially parallel and roughly 2¼ inches apart (corresponding to the human interpupillary distance). (3) A ringstand and its clamp, of the type found in almost any physics laboratory, are temporarily put into use at the time when the photographs are to be viewed stereoscopically. This equipment is used to hold the home-made stereoscope lenses and frame in place at the proper distance (in view of the focal length of the lenses) above a laboratory table on which the photos can be viewed while the observer is looking vertically downward through the lenses.

If any interested reader cares to follow this simple and inexpensive procedure he most certainly will be rewarded when using his resulting stereoscope to view overlapping photos such as those appearing in Figure 19. On so doing he will realize, perhaps for the first time, how tremendous is the increase in information that he can derive from the photographs by virtue of the 3-dimensional image which he perceives through the stereoscope.

The innovative physicist also will realize that aerial photographs taken from a remotely piloted aircraft can be easily and economcally subjected to machine analysis. Since the emphasis in this "do-it-yourself" section of my paper is on the use of simple, inexpensive equipment and techniques, suffice it to say that only the following ingredients are necessary when performing a machine-assisted analysis of photos such as those appearing in Figures 12-19: (1) a simple, laboratory-made microdensitometer of suitably small "spot size" (e.g. 0.01 inch) for use in scanning a photograph, line-by-line and element-by-element; (2) a device for recording these density values in digital form and in proper sequence (e.g. on a magnetic tape); and (3) a simple computer which can be programmed to provide a map-like computer paper "print-out" of these various resource features, based on a machine analysis of the digital records of their previously-calibrated tone values. (Figure 19). As with examples of the <u>human analysis</u> of remote sensing imagery (e.g.,

Figures 12-18) so this computer-assisted analysis can find important practical applications.

SUMMARY AND CONCLUSION

In this paper an attempt has been made to describe various ways in which the basic principles of physics are finding practical application in the fast-growing field of remote sensing. The paper does not purport to disclose any hitherto unknown principles of physics. It is believed that the material which it covers should nevertheless be of interest to physicists in general and especially to physics teachers because it deals with an unusually intriguing field. Further, it is a field which, in its many ramifications, exploits the latest state-of-the-art applications of physics in highly beneficial ways.

Under four major headings consideration is given in this article to the basic principles of physics that are applied, respectively, in (1) remote sensing platforms, (2) remote sensing devices, (3) the analysis of remote sensing imagery by humans, and (4) the analysis of remote sensing data by machines. It is apparent that progress in each of these four areas, whether past, present or future can properly be considered as depending primarily on our understanding of the basic matter and energy relationships (i.e., the basic principles of physics) that are involved.

In a concluding section of this paper, consideration is given to the very attractive possibilities for physicists to engage in meaningful and economical remote sensing endeavors on a "do-it-yourself" basis.

It is apparent, even from the limited information presented in this paper that most of the progress in the field of remote sensing has occurred in the two decades that have elapsed since the dawning of the space age. Such progress, like that in most other aspects of this country's space program, would not have occurred without the dedication and brilliance of a large number of physicists.

There are those who have severely criticized the fact that the talents of so many competent physicists have been funnelled into this "narrow" field of activity. They speculate on the greater amount of good that might have resulted had this massive amount of talent been devoted to various other projects, each having a more worthy objective than that of "satisfying

America's ego by beating the Russians to the moon." On the presumption that there was no other motivation of consequence for our vigorously pursued spage program, they dismiss as being "trivial by-products" or "spin-offs" the remarkable developments that the Space Age has brought about in numerous other fields, such as remote sensing.

In contrast with these critics are strong proponents of this country's space program of the past two decades, including a major component of it - the remote sensing program. They claim that this program has constituted a prime example of science at its best. They applaud the fact that so many competent physicists and other scientists have been "diverted" into this country's massive, peace-oriented effort to explore space and photograph the Earth. When they reflect upon the achievements made possible through this collective endeavor they obviously experience the same exhiliration that was experienced some 23 centuries ago by the great scientist and philosopher, Aristotle, which prompted him to exclaim"

"The search for truth is in one way difficult and in another easy. For no one can master it fully, nor escape it wholly. But each, through his own efforts, adds a bit of information, and from the mass of knowledge thus assembled there arises a certain grandeur."

It is probable that, in the years to come, there will be a reconciliation of these two widely divergent views regarding the merits of our nation's space program in general, and of its remote sensing program in particular. If so, it will almost certainly come about as a result of an increased appreciation of the benefits being realized by all of mankind - e.g. benefits resulting from wiser management of the earth's natural resources and better preservation of man's environment, made possible because of the availability of more accurate and more timely information about them - benefits that would never have come about had not a host of highly competent and dedicated physicists applied their collective talents in helping to develop the multifaceted field of remote sensing.

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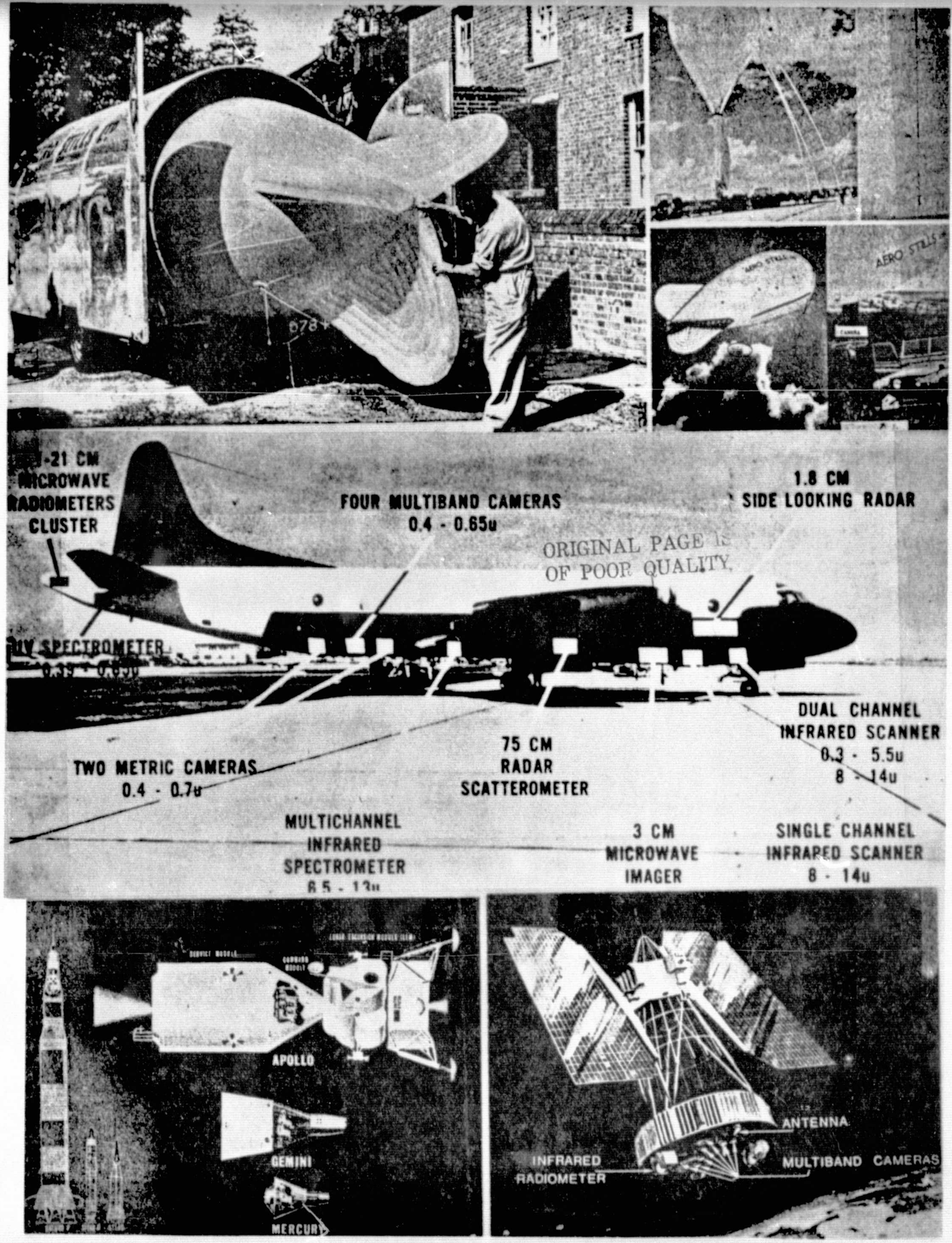

Figure 1. Representative types of remote sensing platforms:
Top: Lighter-than-air craft; Middle: Heavier-than-air craft; Bottom: spacecraft.
See the accompanying text for a discussion of certain principles of physics
that are involved in the flight of these dramatically different types of vehicles.

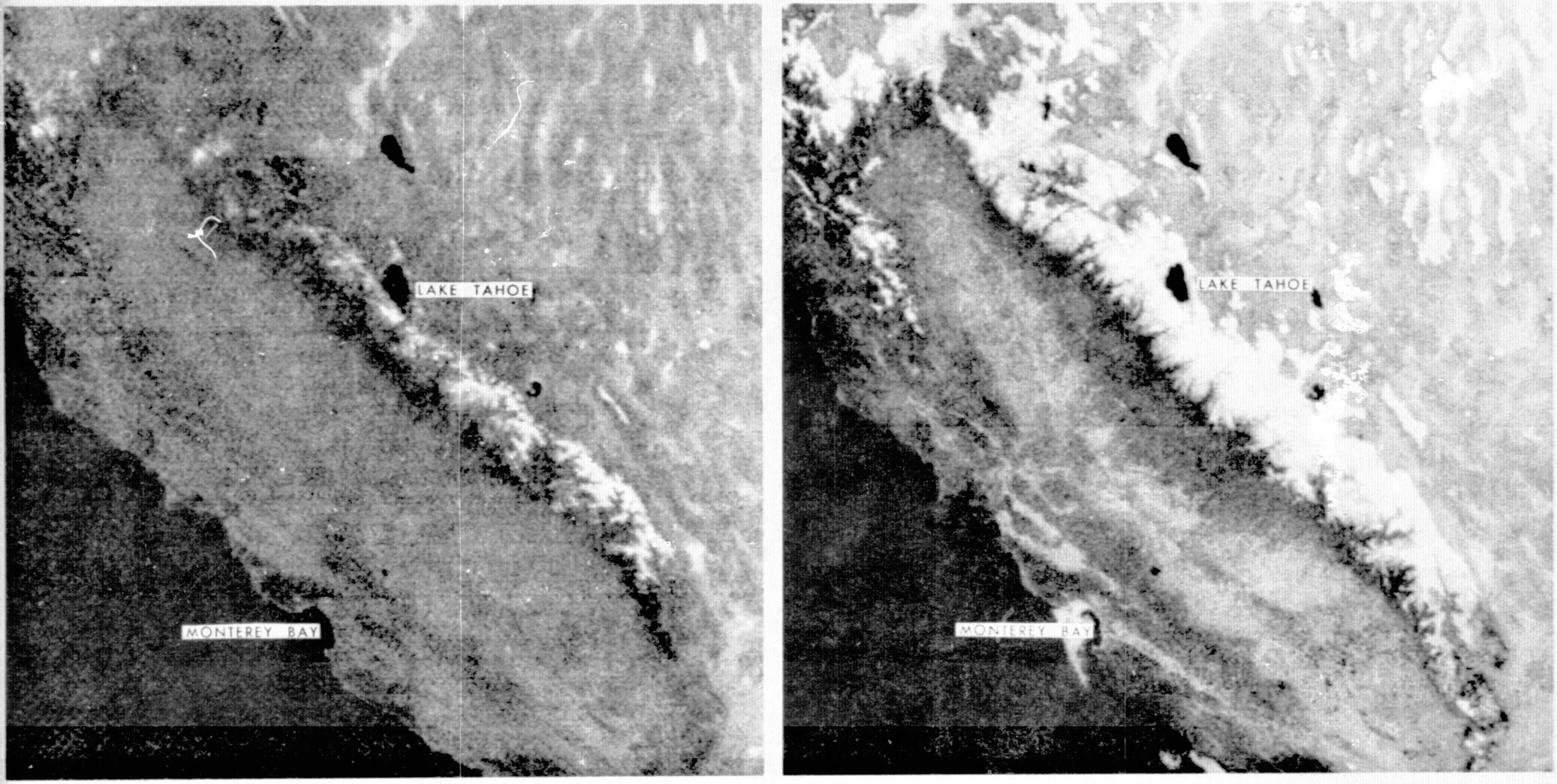

Figure 2. These two space photos were taken of California and its environs from a geo-synchronous satellite (NOAA-5) from an altitude of more than 23,000 miles. Note from a comparative study of these photos that the snowpack in the Sierra Nevada Mountains was much greater on April 28, 1975 (left photo) than on April 19, 1977 (right photo), foreboding what proved to be "the worst drought in California history", which occurred in the summer of 1977.

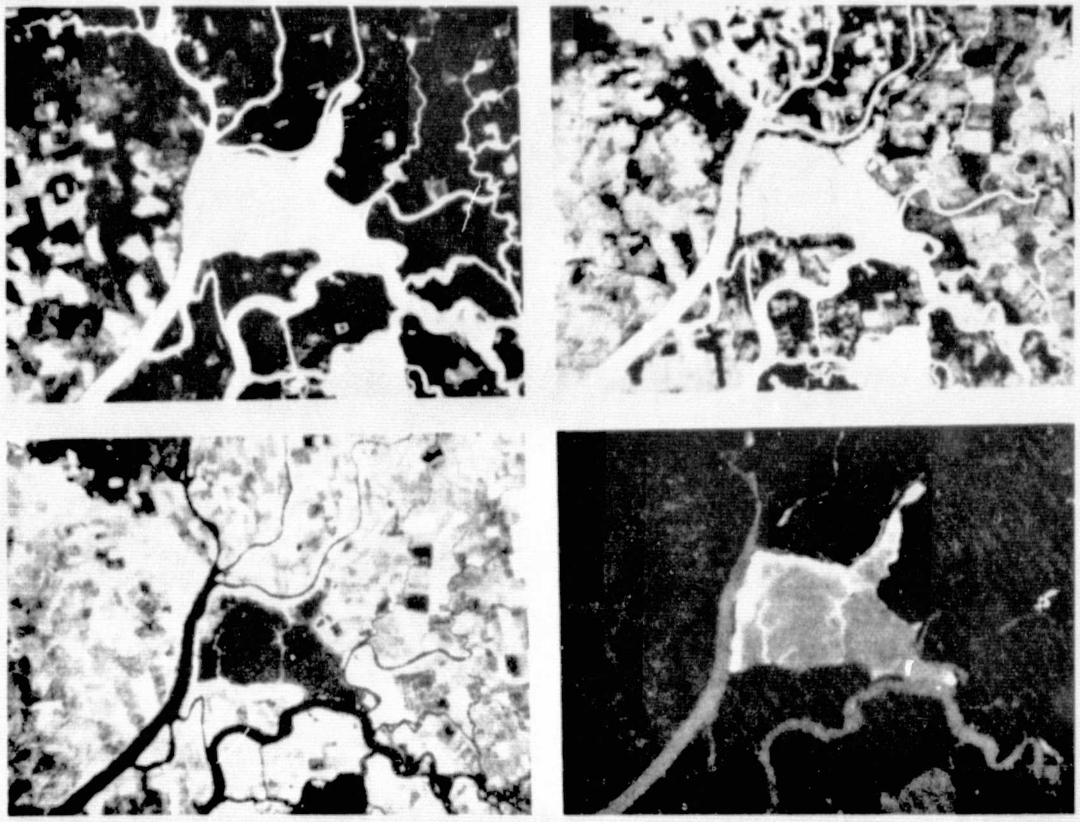

Figure 3. These four Landsat space photos show the flood waters receding from an agricultural area in the Great Central Valley of California. All four photos were obtained from Band 7 (a near-infrared-sensitive band) of the multispectral scanner. Top left: Negative rendition of the image acquired on July 26, 1972. Top right: The same area as photographed by Landsat 36 days later. Bottom left: A positive rendition made from the negative image that appears in the top right illustration. This rendition was made so that it could be superimposed over the negative transparency made from the top left illustration, thereby facilitating "change detection." Bottom right: The composite image resulting from this superimposing of images. Note that the light-toned areas indicate the areas from which flood waters have receded during the interim.

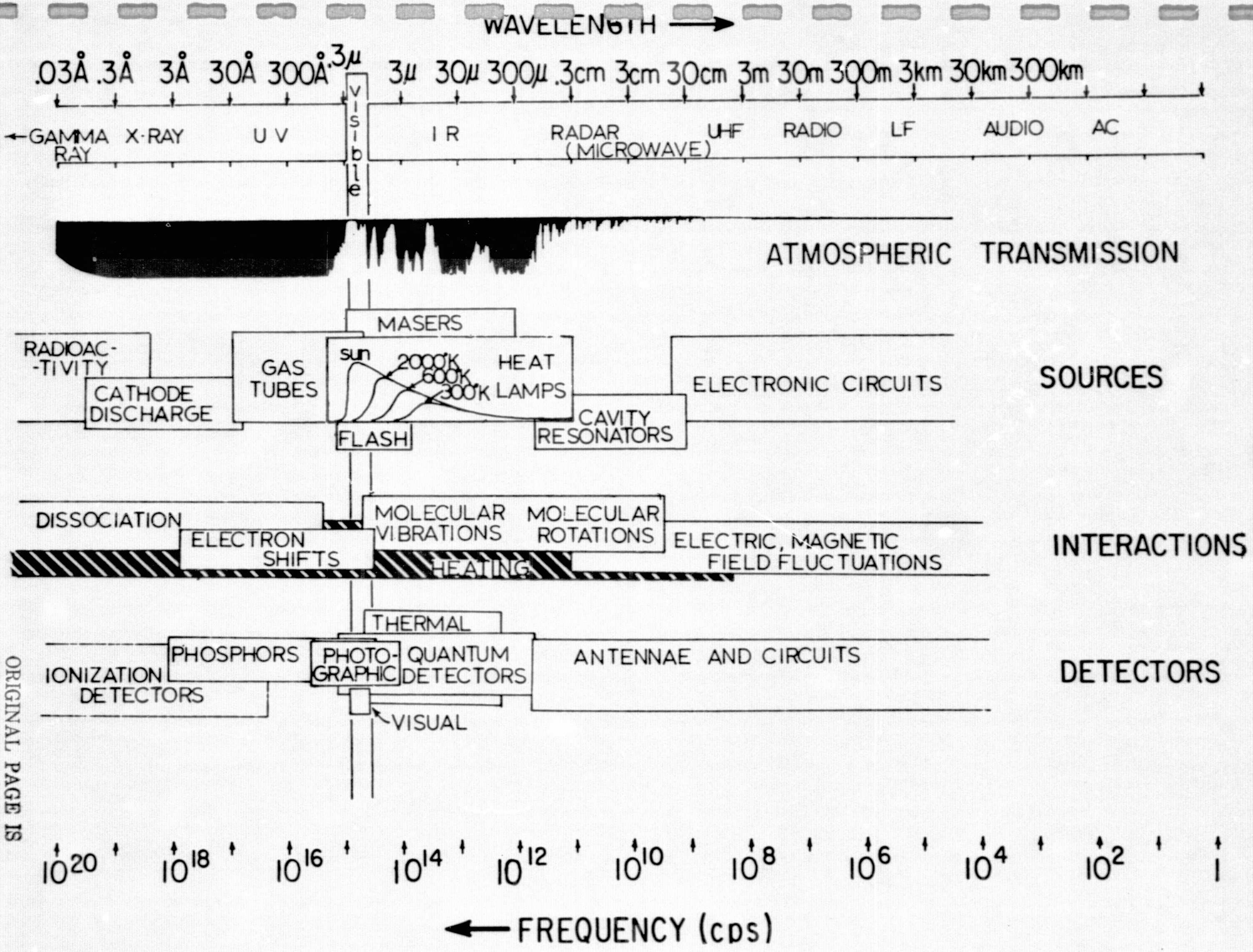

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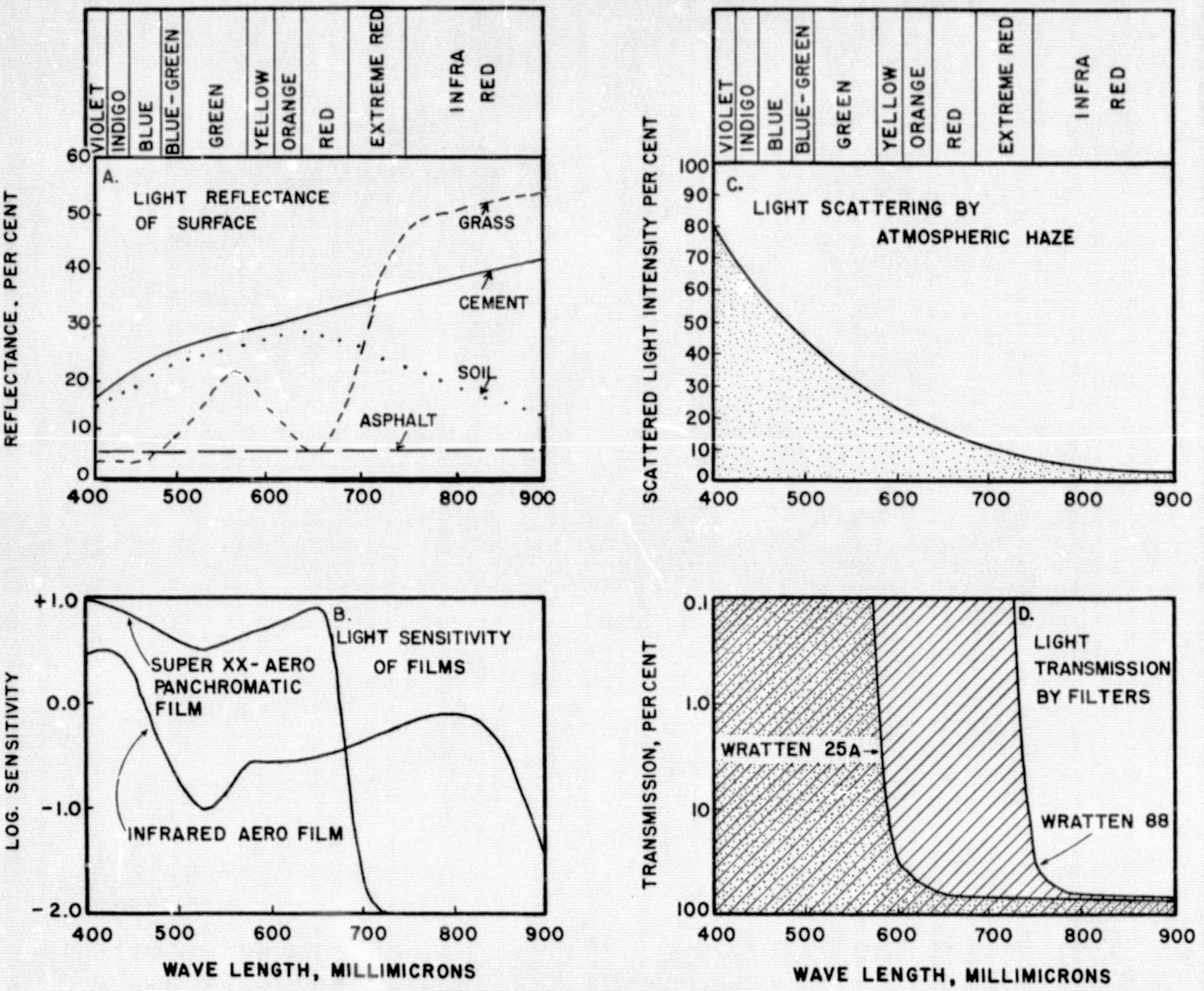
Figure 4. Shown here are many characteristics of the electromagnetic spectrum that serve to relate the basic principles of physics to the practical applications of remote sensing, as discussed in the text. (From Colwell, et. al., 1963).


VIOLET
INDIGO
BLUE
BLUE-GREEN
GREEN
YELLOW
ORANGE
RED
EXTREME RED
INFRA RED
A.
LIGHT REFLECTANCE OF SURFACE
REFLECTANCE, PER CENT
GRASS
CEMENT
SOIL
ASPHALT
B.
LIGHT SENSITIVITY OF FILMS
LOG. SENSITIVITY
SUPER XX-AERO PANCHROMATIC FILM
INFRARED AERO FILM
C.
LIGHT SCATTERING BY ATMOSPHERIC HAZE
SCATTERED LIGHT INTENSITY PER CENT
D.
LIGHT TRANSMISSION BY FILTERS
TRANSMISSION, PERCENT
WRATTEN 25A
WRATTEN 88
WAVE LENGTH, MILLIMICRONS

TYPE OF SURFACE	PREDICTED TONE ON POSITIVE PRINTS	
	PAN - 25A	INFRARED-89A
GRASS	DARK	LIGHT
CEMENT	LIGHT	LIGHT
ASPHALT	DARK	DARK
SOIL	LIGHT	DARK

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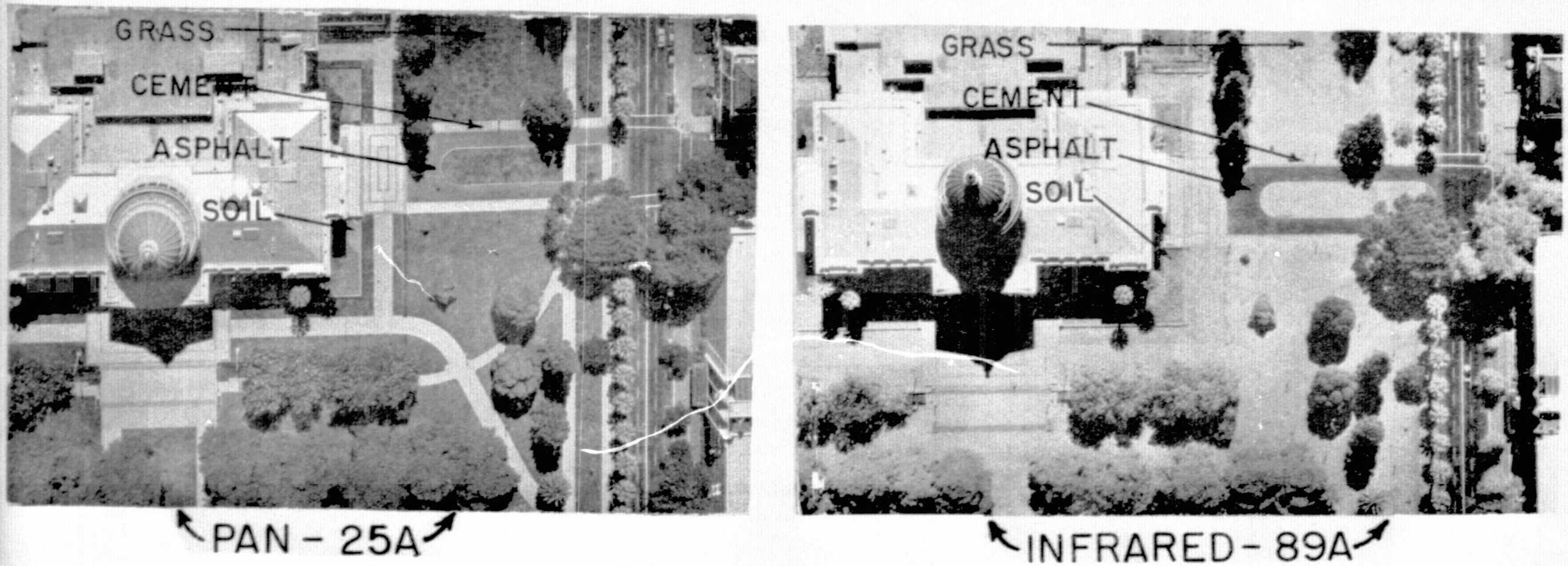

Figure 5. An example of the use of certain basic principles of physics in correctly predicting the 2-band "photographic tone signature" of various features, as discussed in the text.

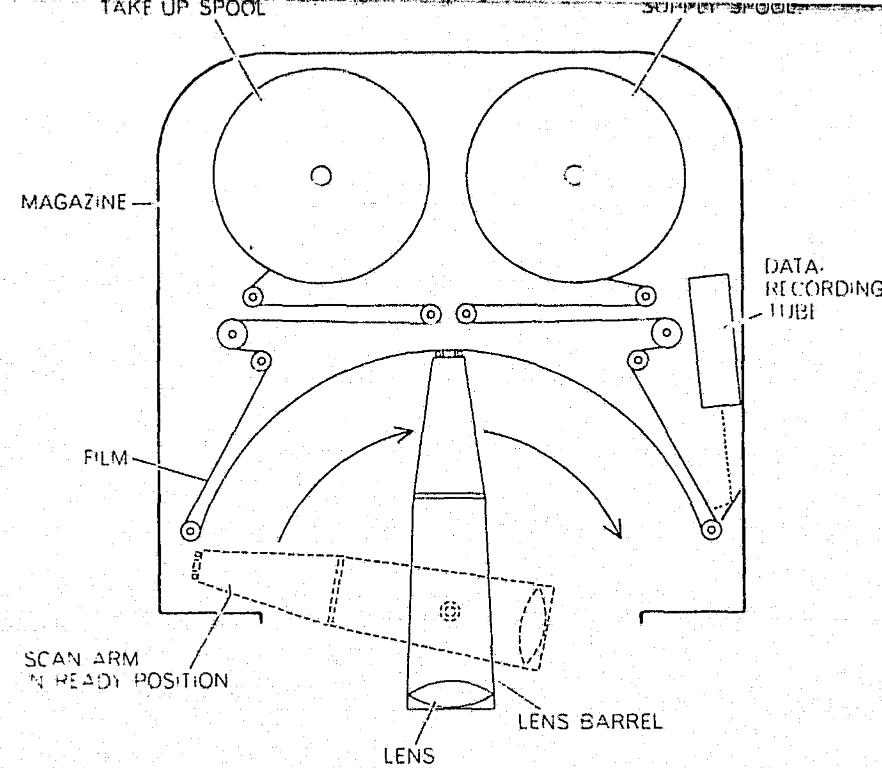

Figure 6. The Panoramic Camera, as diagrammed here, was developed to provide sharp aerial photographs of large scale. Since the camera must have a long focal length it must also have a narrow angular field to ensure that lens aberrations will be minimal. As a result it requires a scanning mechanism that moves the lens barrel to left and right. At any instant during the course of a scan only light passing through a narrow slit falls on the film.

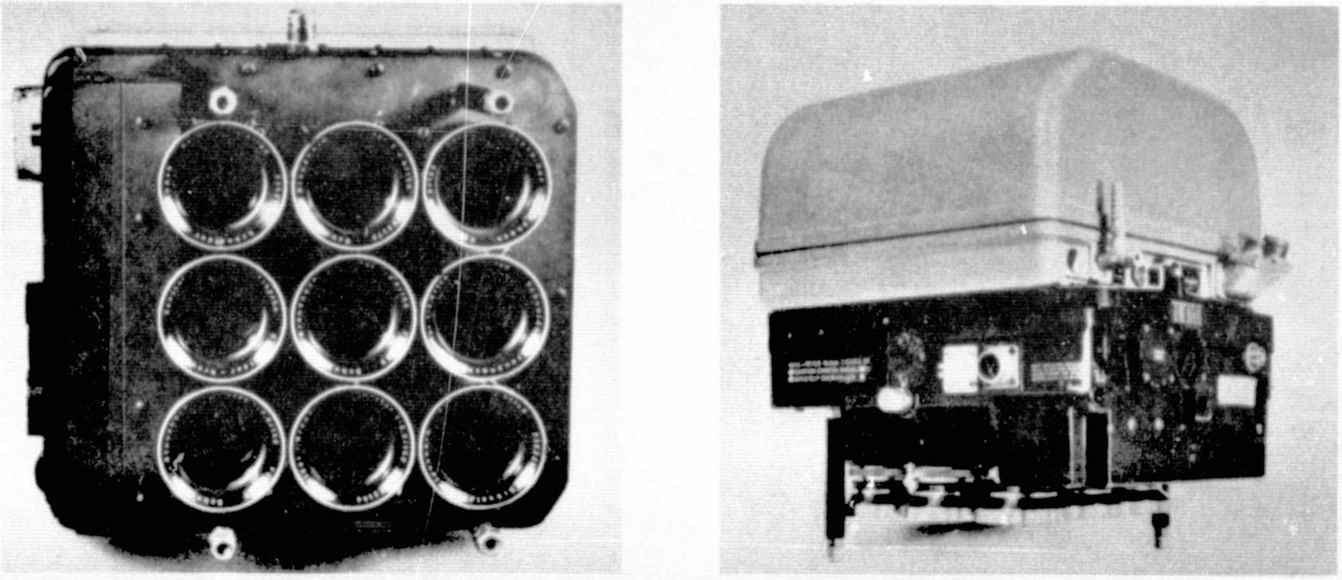

Figure 7. This is one of many different multiband camera models. It has nine lenses and nine film-filter combinations, each designed to function best in one part of the spectrum. Such a camera permits more positive identifications to be made of certain natural resources from their multiband "tone signatures".

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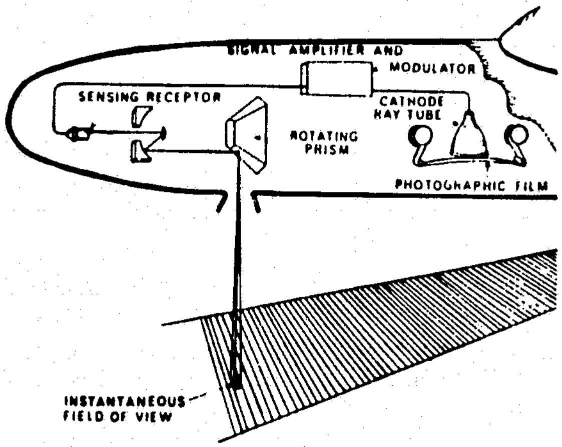

Figure 8. This diagram highlights the physical principles that are embodied in an optical mechanical scanner of the type used in obtaining thermal infrared imagery. For further explanation, see text.

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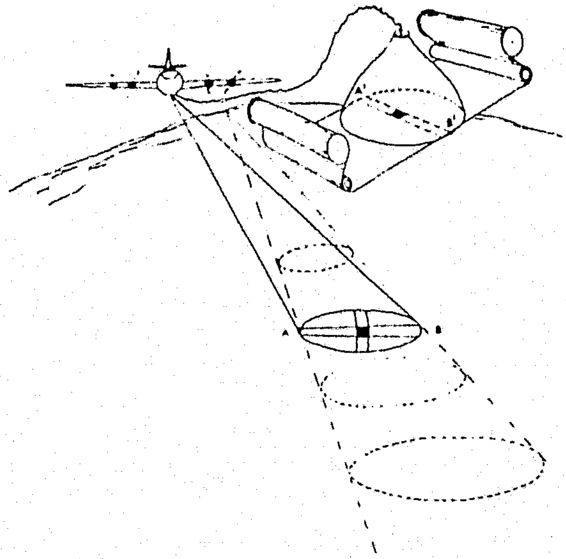

Figure 9. This diagram highlights the physical principles that are embodied in Side Looking Airborne Radar (SLAR) equipment, as discussed in the accompanying text.

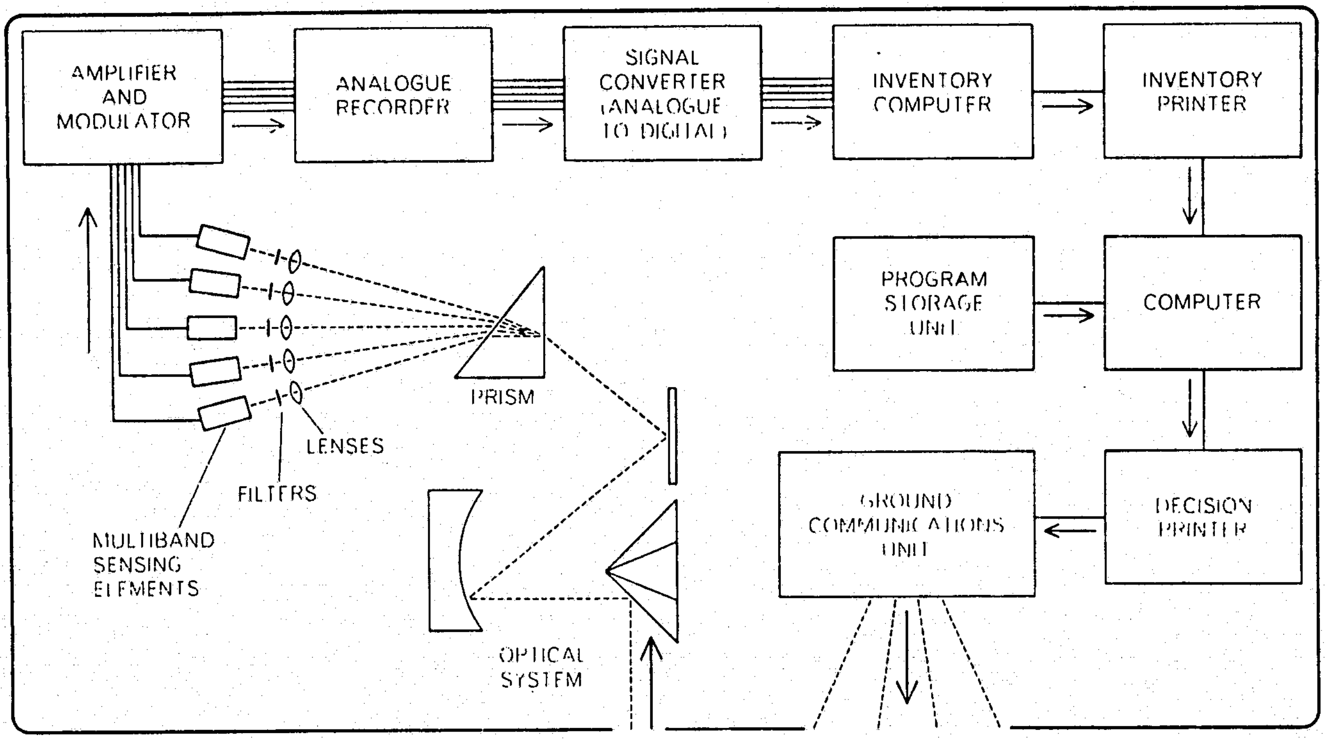

Figure 10. This futuristic diagram shows the ultimate possiblities for exploiting basic principles of physics in remote sensing activities that are designed to facilitate the inventory and management of earth resources. It would sense such resources simultaneously in several wave bands, automatically identify them by means of an "inventory computer", weigh them against previously programmed data on the cost effectiveness of various management possibilities, and send to the ground a decision on what should be done. It also might be used to monitor developing situations, such as a forest fire, suggesting how ground crews might fight it, and to perform automatically such tasks as turning irrigation valves on and off as required.

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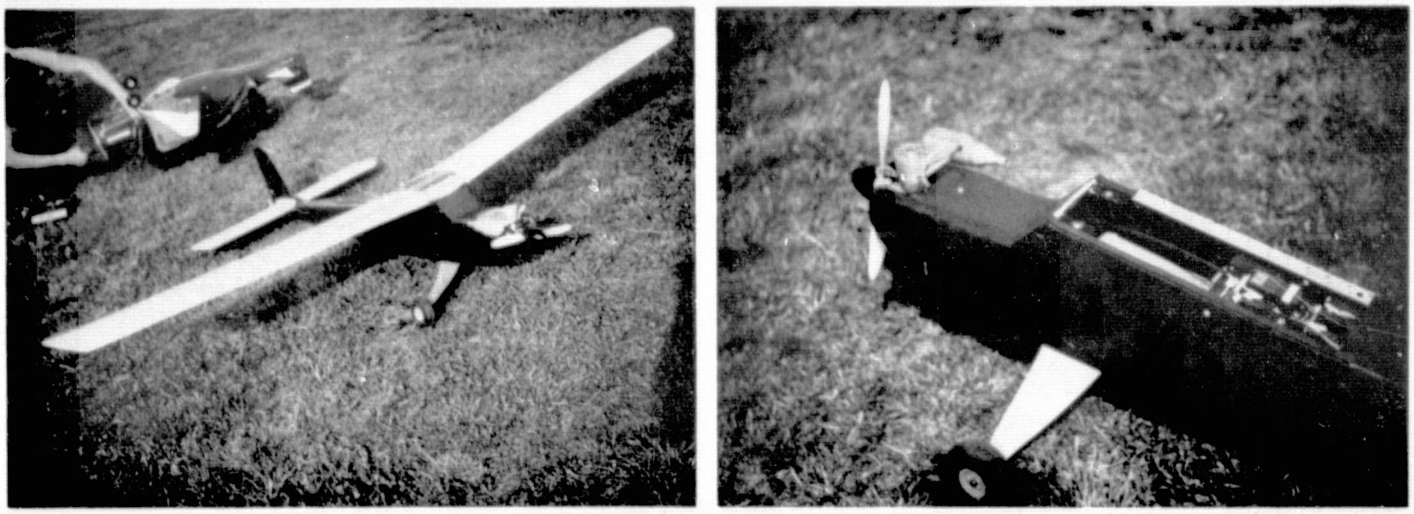

Figure 11. These two photos show a remotely piloted photographic aircraft that was built from a modified Telemaster model airplane kit by a remote sensing enthusiast who had an adequate understanding of the basic principles of physics. (Sheppard, 1976, 1977). For examples of the uses that can be made of aerial photographs taken from this type of "platform", see Figures 12-19.

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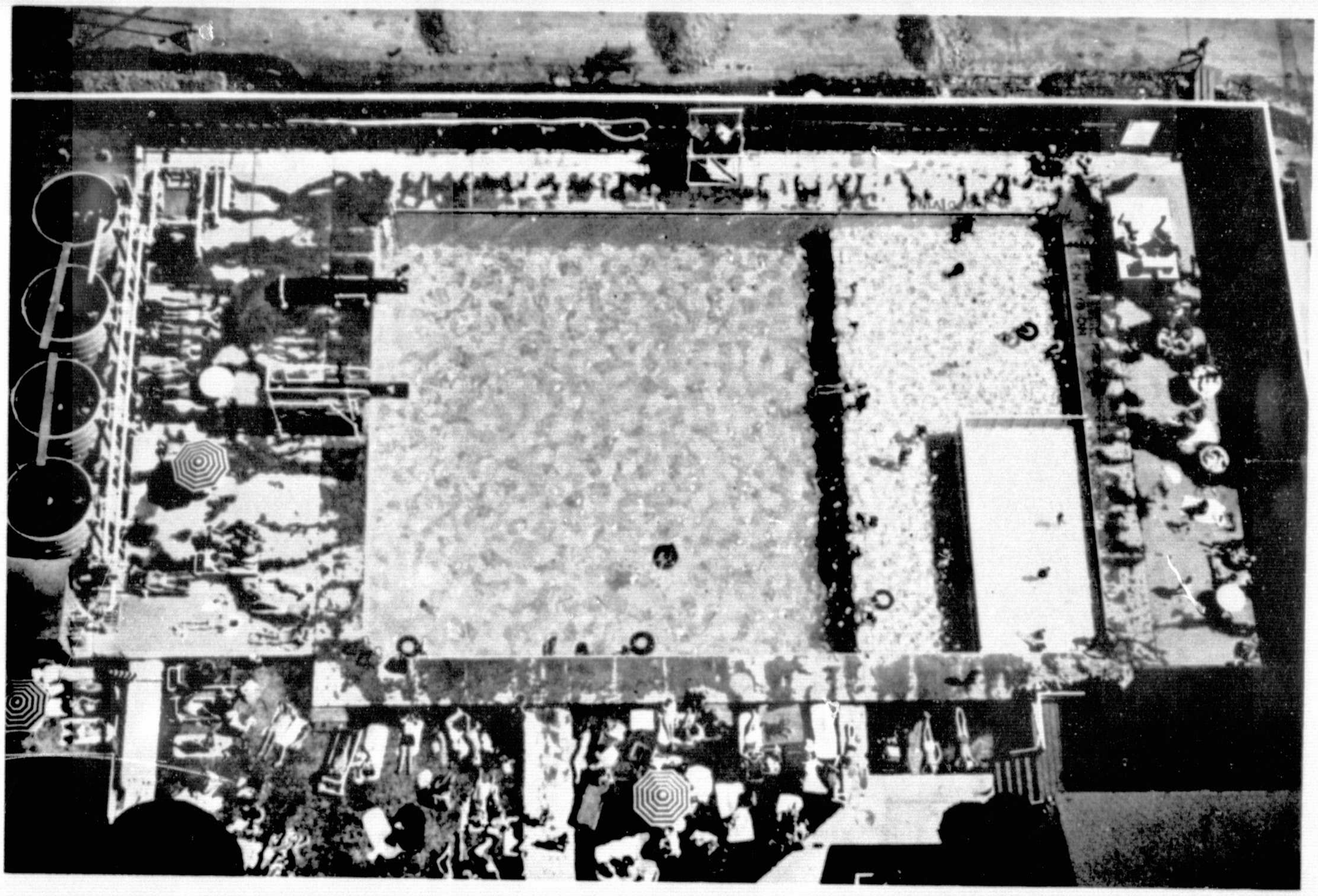

Figure 12. For a physicist whose hobby it is to build a small model airplane and equip it with a camera (as in Figure 11) the taking of remotely-piloted near-vertical aerial photos such as this one of the community swimming pool can only be categorized as "fun". As a caution, however, against hazards that might result from mechanical failure of the aircraft, he usually would be well advised, as in this instance, not to fly the drone aircraft directly over a populous area.

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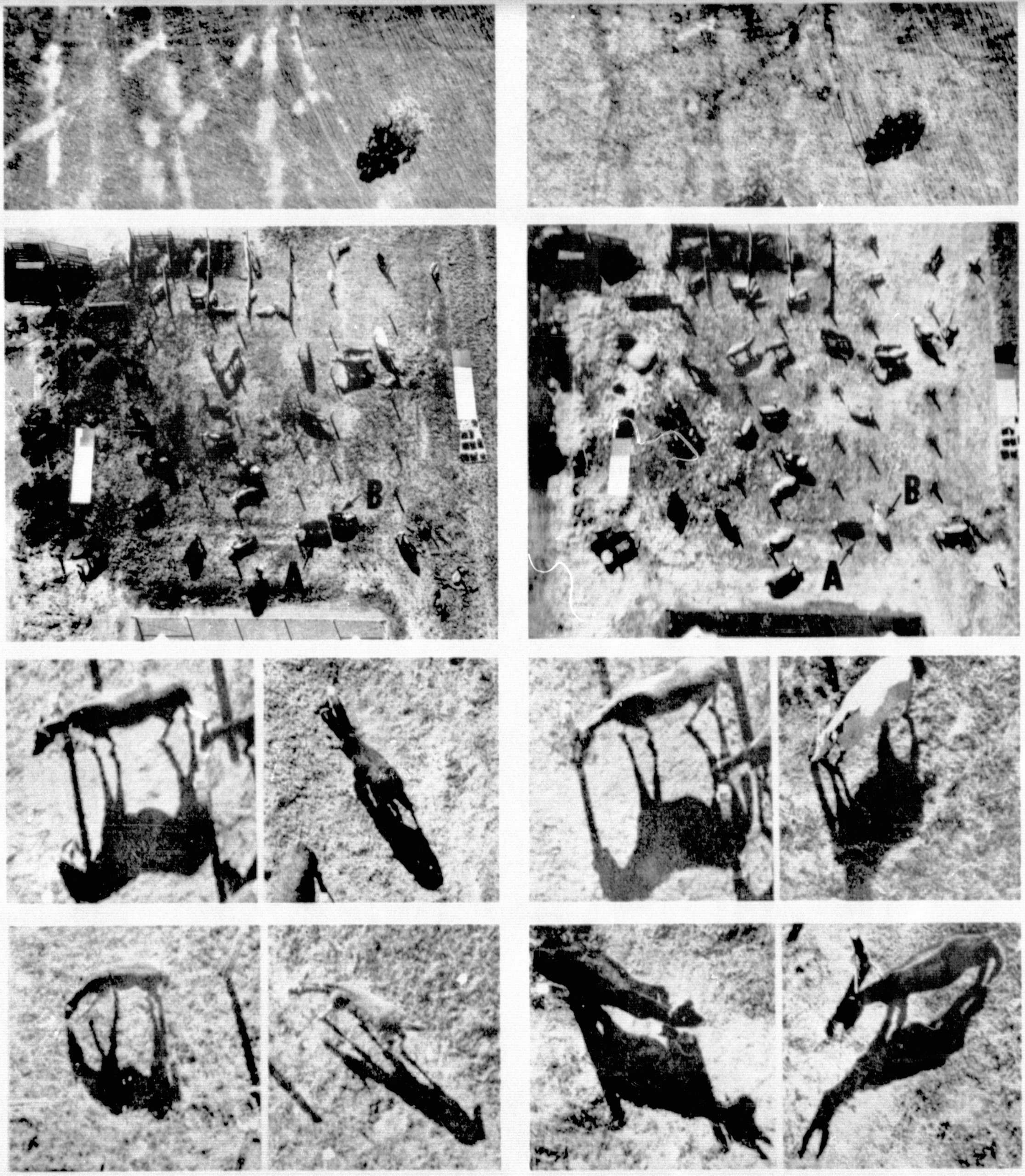

B
A
B
A

Figure 13. As illustrated by these examples, ordinarily there should be little difficulty in using a small remotely-piloted aircraft to photograph rangelands, pasturelands, and the livestock which they support. Photos 1 and 2 of this figure were taken within a few minutes of each other, but with panchromatic and infrared-sensitive films, respectively. The light toned areas in the rangelands of photo No. 1 are those in which hay has been strewn from a wagon as supplemental feed for cattle. Note that it would be much more difficult and perhaps impossible to determine on the matching infrared photo (No. 2) that an adequate supply of supplemental feed was still present in the area. Photos 3 and 4 also were taken with panchromatic and infrared-sensitive films, respectively, showing many types of livestock, most of which were tethered to posts to facilitate image comparisons in this simple photo interpretation experiment. Note that, in this instance, the infrared photograph is superior for differentiating breeds of beef cattle as seen, for example, by comparing the "hereford" at B with the "hereford angus cross" at A. Also shown in these two matching photographs are pigs and sheep (top left), goats (top right), thoroughbred horses and quarter horses (top center), dairy and beef cattle (middle and bottom center), and a jack-ass (bottom left). From 4-diameter enlargements of selected portions of this "target array" (as seen in Photo pairs 5AB through 8AB) the potential value of shadows as an aid to livestock identification can be seen. In the left photo of each such pair, the main axis of the animal is more nearly perpendicular to the sun's rays than in the right photo with the result that shadow details are of greater diagnostic value. Photo pairs 5, 6, 7 and 8 show image examples, respectively, of thoroughbred horses, quarter horses, colts, and jack-asses.

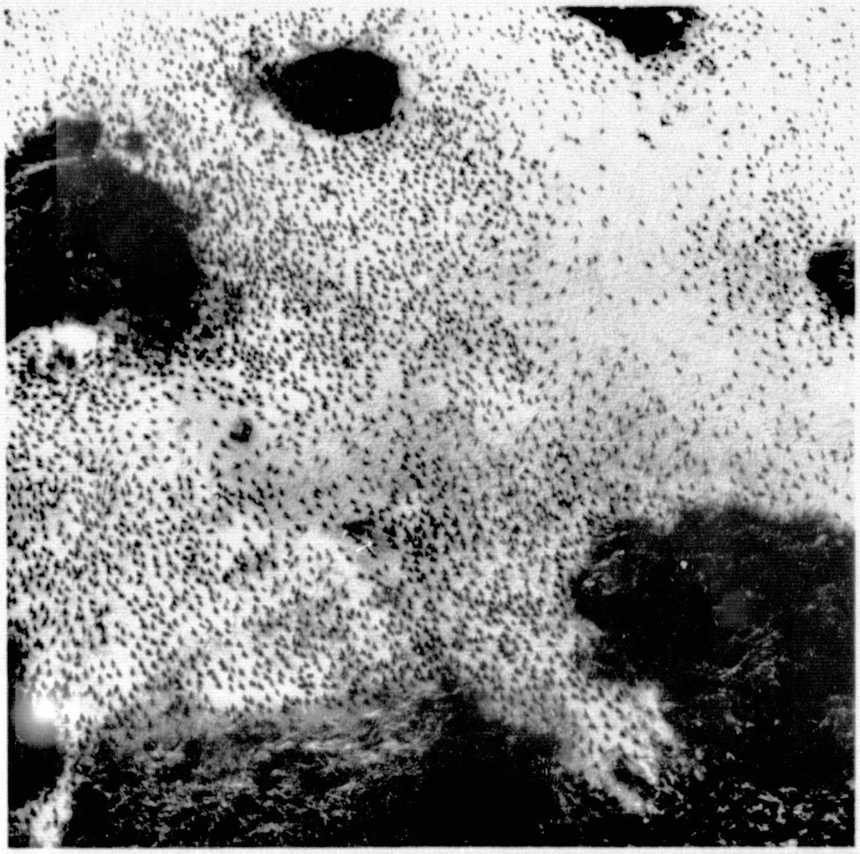
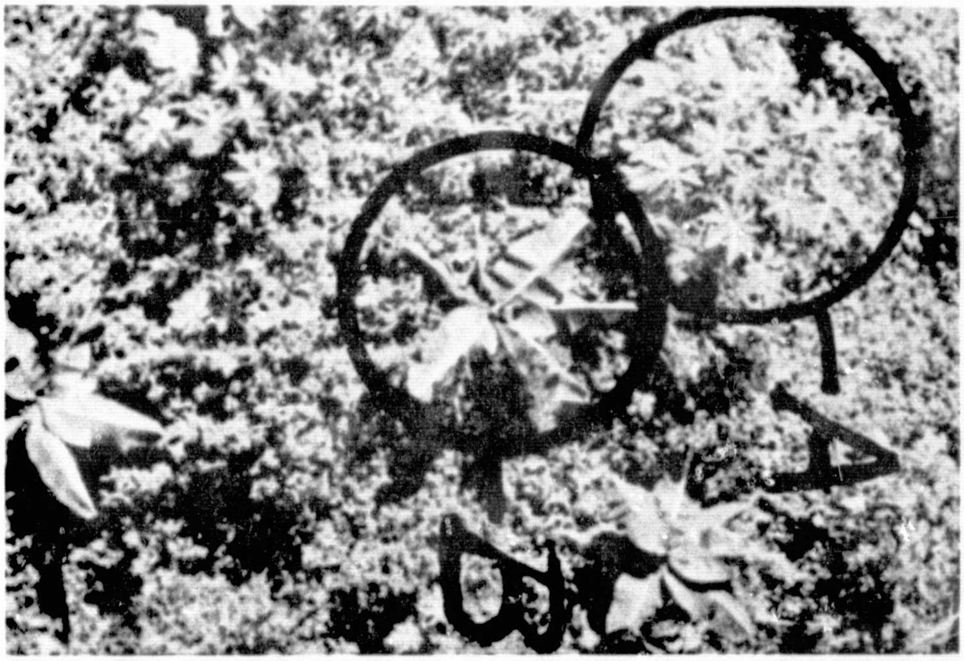
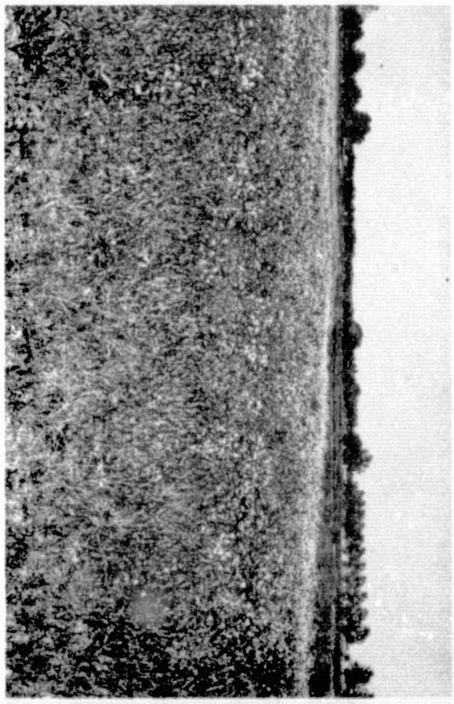


Figure 14. The objective of this large scale, low altitude photograph was to count the number of waterfowl (ducks) in a representative portion of their wintering grounds. This was done as part of a year-to-year program for the monitoring of this important resource. A small and relatively quiet drone aircraft can be remotely piloted over such an area so that aerial photographs can be taken without startling the birds. In contrast, by the time a large and much noisier piloted aircraft is making its low-altitude pass over the area it is quite common for the birds already to have been startled by it and to have taken flight. Consequently accurate bird counts are difficult to impossible to make on the resulting photographs.


A
B



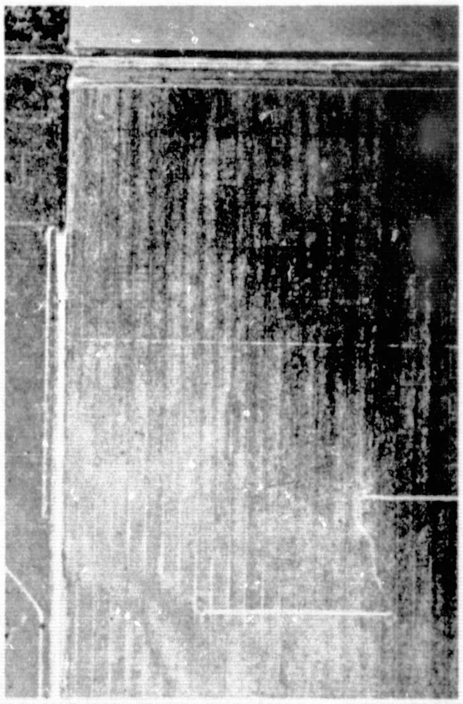


Figure 15. On a very large scale, low-altitude, vertical aerial photograph (such as the one on the left, taken of a narrow valley bottom in Hawaii) there is sufficient detail to identify species of vegetation from their leaf characteristics and/or branching habits. In this instance it is possible to see and identify individual papaya trees, including those encircled at A, and to differentiate them from banana trees such as the one circled at B. In many instances, including this one, important natural resources are found in box canyons or other tightly confining topography. Such areas are much more easily and safely photographed at low altitude by a small, highly-maneuverable remotely-piloted aircraft than by a conventional aircraft. On the low altitude vertical photo at top right, the lighter toned portions of of the barley fields are seen to be heavily infested with weeds, in this case mustard plants (Brassica nigra). Although the bottom right photo was taken from ground level of the same field and on the same date, there is much less information on that "farmer's eye view" than in the matching "bird's eye view" immediately above it. Hence this example suggests that the farmer might well be a potential user of low altitude vertical aerial photographs of the type that could be economically and safely flown of his fields with a camera-equipped, remotely-piloted aircraft of the type shown in Figure 11. All of the photos shown in this figure, as in many others of this series, are enlarged from 35 mm photography.

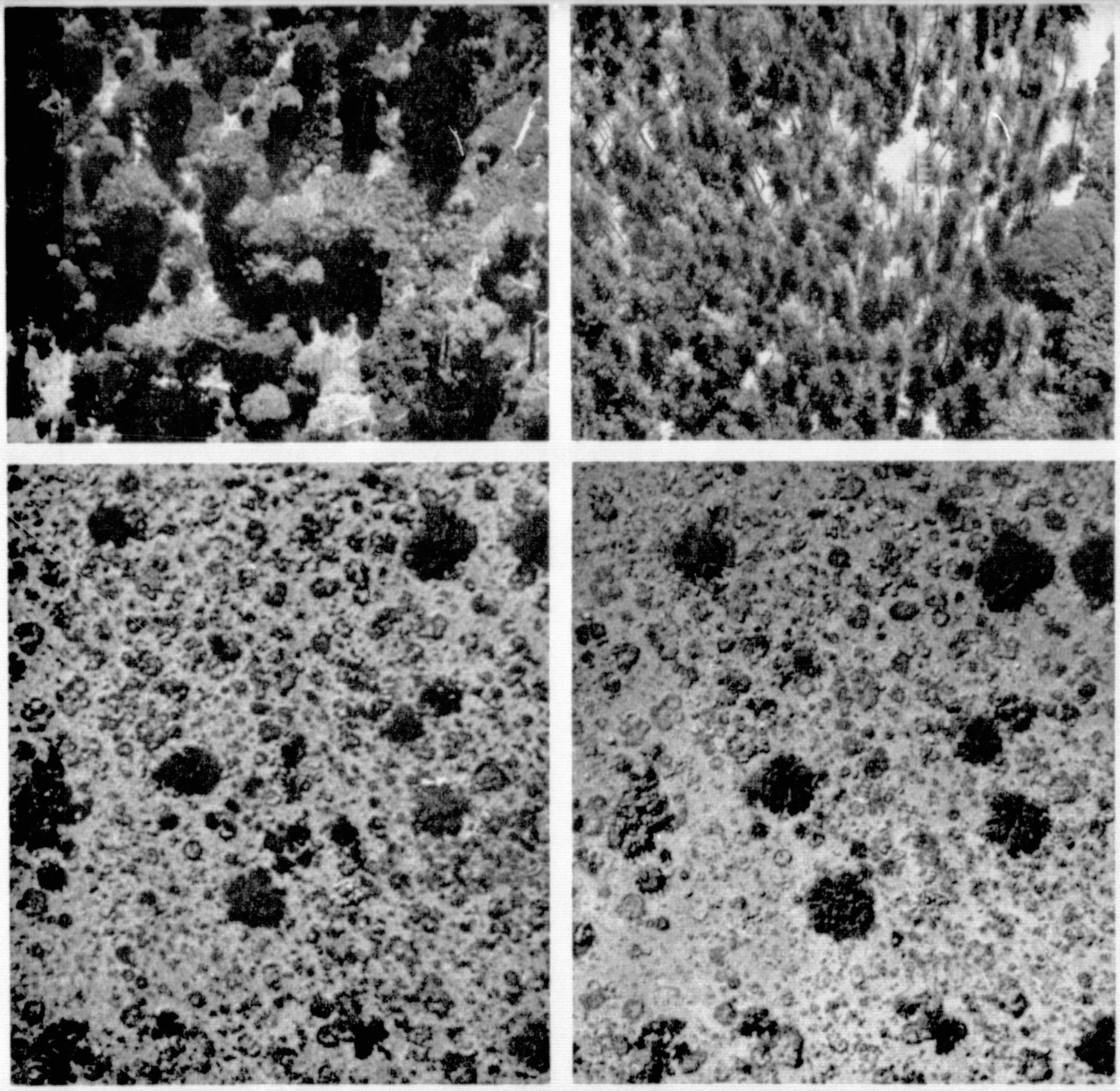


Figure 16. Low altitude vertical photographs of forest lands and rangelands are shown in the top and bottom photos, respectively, of this figure. In the top left photo, taken in California's Sierra Nevada Mountains, one can readily differentiate most of the fir trees with their conical tops (note their shadows) from sugar pine trees with their somewhat star-shaped tops (note their large individual branches). In addition the amount and location of underbrush and of fallen timber can be seen quite readily. In the top right photo, most of the insect-infested trees are already exhibiting chlorotic (yellow-to-brown) needles and hence can be differentiated from their healthy associates. The bottom left and bottom right photos, taken in July, 1967 and July, 1969, respectively, show native perennial forage species in a range allotment in northeastern California at the fringe of the Great Basin sagebrush type. The largest shrubs, known as "bitterbrush" (Purshia tridentata) are highly palatable to both cattle and deer. Note the dramatic increase in shrub size during the two-year interim resulting from the fact that only "rest-rotation" grazing was allowed in the area. Similar photos taken of an adjacent area in which there were no restrictions on grazing showed that there was virtually no net growth of the highly desirable shrubs during the interim. Such information is much more easily obtained from large scale vertical aerial photos than by other means. By far the least expensive and safest way of getting these very low altitude photographs for areas of small size and at some distance from the nearest airfield is through use of a remotely-piloted aircraft equipped with a 35 mm camera.

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Figure 17. The left photo shows glacier ice and snow fields in Alaska that are often hazardous to fly over at low altitude but for which current large scale photographs such as this may be needed by those seeking to traverse the area but unaware of present conditions in terms of crevasses and other hazards to movement. The right photo is of the type needed for monitoring oil slicks (the light tone areas) or small boat traffic (accentuated by boat wakes). Here, then, are two other examples of situations in which the safest and/or most economical means of obtaining the desired photography might be through the use of a small, remotely-piloted photographic aircraft, such as the one shown in Figure 11.

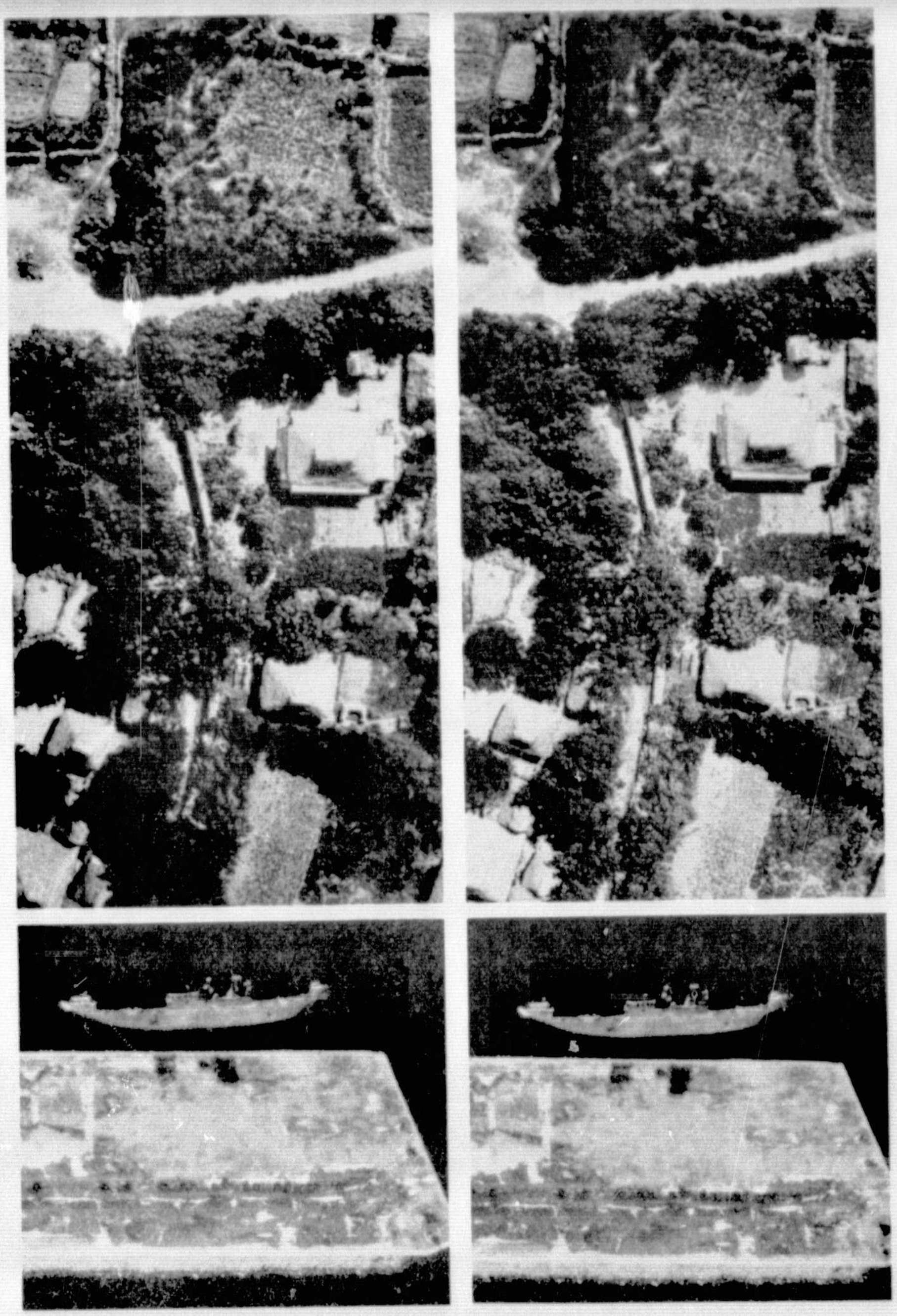

Figure 18. If, as described in the text, the physics hobbyist were to build a simple, lens-type stereoscope and attach it to a ringstand, he could then examine these two low altitude stereo pairs of photographs 3-dimensionally. On so doing, he would most certainly be impressed by the greatly increased amount of information that he could gain from the photos, including the configuration of thatched-roof huts in the top stereogram and the presence of cranes near the storm-damaged and sunken ship in the bottom stereogram.

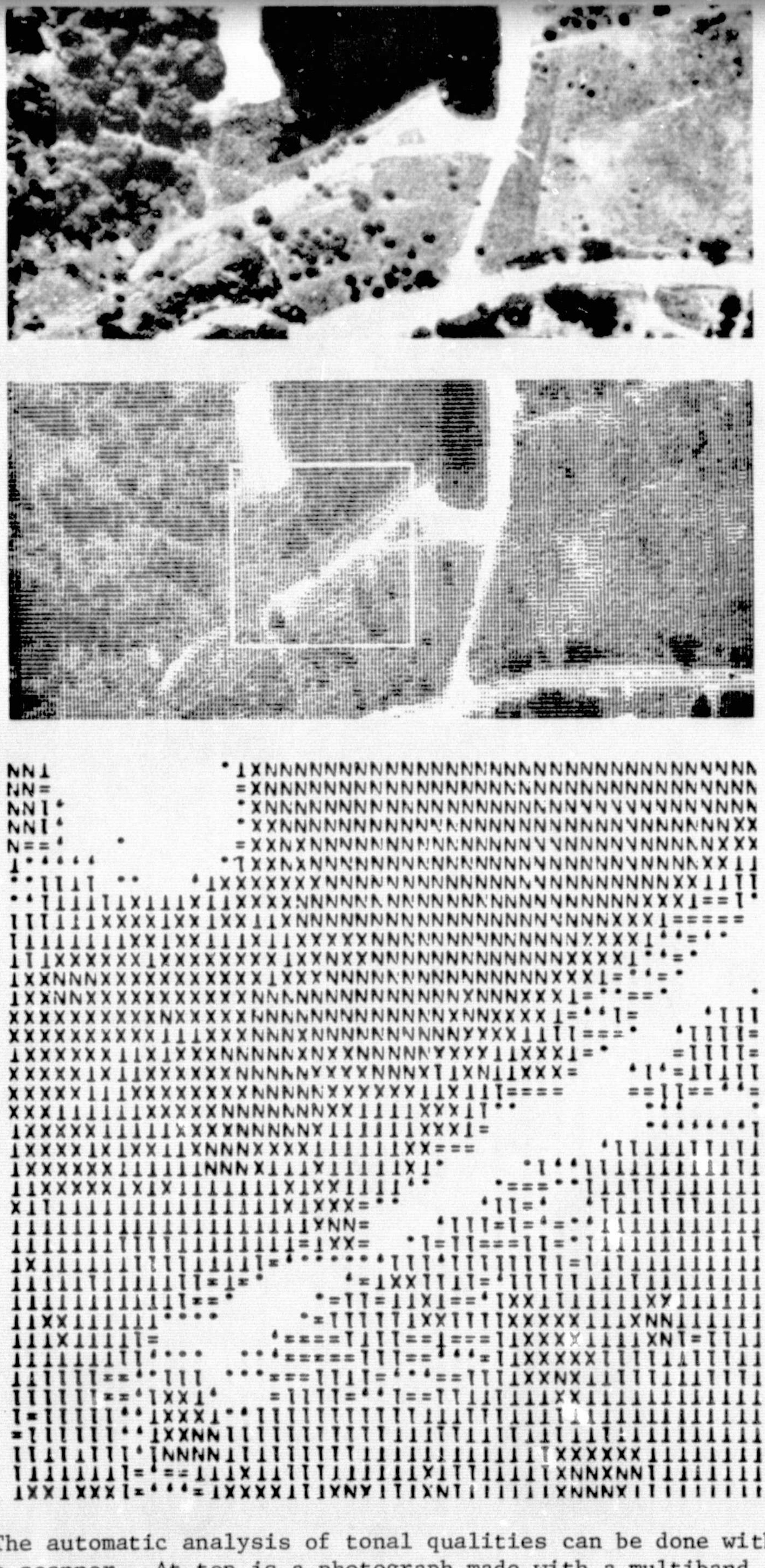

Figure 19. The automatic analysis of tonal qualities can be done with a photoelectric scanner. At top is a photograph made with a multiband camera. At center is a scanner's print in which "N" shows darkest tones and other symbols represent lighter tones. At bottom is an enlargement of the outlined area. Since each natural resource tends to have a unique multiband tone signature, automatic encoding of tones may lead to automatic resource inventories.

Special Study No. 3

SATELLITE LAND USE ACQUISITION AND APPLICATIONS TO HYDROLOGIC PLANNING MODELS

by

Ralph Algazi

and

Minsoo Suk

Department of Electrical Engineering
Davis Campus
University of California

(Note: See explanatory statement on page 4-1 with reference to the material included in this Special Study)

SATELLITE LAND USE ACQUISITION AND APPLICATIONS TO HYDROLOGIC PLANNING MODELS**

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ABSTRACT

In this paper, we report on a developing operational procedure for use by the Corps of Engineers in the acquisition of land use information for hydrologic planning purposes. The operational conditions preclude the use of dedicated, interactive image processing facilities. Given the constraints, an approach to land use classification based on clustering seems promising and is being explored in detail. The procedure is outlined and examples of application to two watersheds given.

1. HYDROLOGIC ENGINEERING PLANNING MODELS

The objective of our work is to develop operational procedures for use by the Corps of Engineers across the United States in the acquisition of land use information. The primary source of data is LANDSAT digital data and the intended use of the land use information is for hydrologic planning purposes. Land use information allows the Corps of Engineers to assess the flood hazard, general damage potential, and environmental status of watersheds. Use of this information is illustrated in a recently completed pilot research Flood Plain Information (FPI) study [1] by the Hydrologic Engineering Center (HEC) of the Corps of Engineers. In the study, data management and analytical techniques, integrating the use of spatial gridded geographic data files (called Grid Cell Data Bank), are incorporated into hydrologic computer models denoted HEC-1 and STORM.

The analysis methods of the HEC study interpret the hydrologic, economic, and environmental consequences of alternative land use patterns in combination with other physical characteristics of the watershed, such as soil class, land slope, erosion index and topography. Land use information is the key factor in performing the analysis in that it is used as the primary indication of the watershed conditions and of its response to precipitation.

The acquisition of land use information by conventional methods such as manual classification using aerial photographs or ground surveys are often time consuming for large watersheds or inadequate, not providing accurate spatial information of land use. Remote sensing data can provide land use information accurately and in a timely fashion for hydrologic planning purposes. By proper use of high speed digital computers, highly accurate and point-by-point information of land use can be extracted from the remotely sensed data.

2. LAND USE CATEGORIES AND REMOTE SENSING FOR HYDROLOGIC APPLICATIONS

Since the land use pattern is an important factor in hydrologic, economic and environmental analysis, the development and use of a reasonable set of land use categories is quite important. Hardy and Anderson [2] have recommended a standard set of land use categories for use with remote sensing data. Ragan [3], in applications to water resources, has used a modified subset of land use categoires* of Hardy and Anderson, and has shown that remote sensing

*Land use categories used by Ragan in his work are: Forested area, highly impervious, grassed area, residential, streets and highways, bare land, streams, ponds or pools.

**Paper presented at the Eleventh International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan. 25-29 April 1977.

data can provide land use information. The land use pattern was then used by Ragan to determine hydrologic parameters in urban hydrology.

On the other hand, we note that the FPI study by HEC has applications to economic and environmental analysis as well as to hydrology. Thus, the objectives and criteria which determine a set of land use categories in this study are different from what was used in previous work. Quoting the criteria applied by HEC to determine a rational set of land use categories:

" • The categories should be reasonably compatible with local and other agency land use classification schemes

• It must be reasonably possible to classify the land use within the study area by conventional or automated means

• The land use categories should allow rational, consistent determination of flood hazard, economic and environmental effects of land use change

• The land use categories should be compatible with those needed by certain available computer models

• The land use categories should provide a complete umbrella of classifications so that further breakdown of land use within each category would be possible if deemed necessary in future studies"

The different concerns in land use for each application are well expressed in another quotation from the HEC report:

> " ... from the hydrologic viewpoint, the concern in a land use sense is with moisture retention/precipitation excess and basin response characteristics which are related to impervious cover and land surface management measures. From the economic viewpoint the damage potential and disruption of community activities is a function of urban development in general and the size, density, and type of structures and contents. From the environmental viewpoint, the concern is mostly with the intensity of development and the potential for adverse impacts (such as pollution) that could derive therefrom."

In the specific application of the FPI study to the Trail Creek Watershed in Georgia, HEC has adopted the set of land use categories shown in Table 1. These categories represent a compromise between the general criteria mentioned above and the technical requirements needed for applications to hydrology and economic and environmental studies.

Note that, for the economic and environmental analysis, detailed land use information in urban areas is quite important, which is not the case for hydrologic analysis. The requirements of accurate urban land use classification, such as differentiation between commercial and industrial areas, and differentiation of housing density of residential areas, are quite difficult to meet from remote sensing data.

3. OUTLINE OF AN OPERATIONAL PROCEDURE

Since the final operational procedure should be easily applicable by the field engineers of the Corps of Engineers, this precludes the use of any dedicated and highly interactive image processing hardware (such as G.E. Image 100 or the Bendix M-DAS System). The procedure should require only a limited number of iterations and not rely on the use of full scale color image display. The emphasis is thus in the use of general purpose computers and line printers for intermediate and final output products.

With these specific objectives and constraints, we have first tried a maximum likelihood classification algorithm to determine whether it can be adapted into an operational procedure. We have encountered several difficulties in using a maximum likelihood classifier. Among these are: (1) The choice of land use categories on which the classifier will be trained: The set of land use categories should be complete in the sense that every part of the watershed should belong to one of these categories. We have found the selection of land use categories difficult. (2) Training areas: To have a reliable estimate of statistics, a

large number of sample points (corresponding to large size training areas) is required. In actual applications, it is not easy to find training areas of large size for certain land use categories (principally in urban areas). Further, the determination of the exact outlines and coordinates on the LANDSAT image for each training field is also difficult in the absence of an interactive color image display.

These difficulties make a maximum likelihood classifier unattractive or impossible as an operational procedure with a minimum amount of interaction. Unsupervised classification algorithms appear to be more suitable to our objectives. The clustering approach is a well known unsupervised classification algorithm, which does not require a priori knowledge of land use categories nor locating training areas. At this stage of our work, we are exploring in detail an operational procedure for satellite land use classification based on the clustering approach. The steps and sources of data for the proposed operational procedure are as follows:

a. Digital Specification of the Watershed. Information on the watershed obtainable from maps, such as the watershed boundary and major roads, is entered on a grid oriented data base using an x-y digitization tablet or by key punching the data on cards.

b. Preprocessing of the Data. The original LANDSAT data is transformed using a principal component or Karhunen Loeve (KL) transformation. Only two of the transform components are required for classification and this step results in a reduction in computing costs. This step is optional and can be bypassed for a small watershed.

c. Clustering. We have implemented and tried a clustering program based on the ISOCLS package developed for NASA Johnson Space Center.

d. Classification. The data is classified after clustering by labeling each cluster as belonging to one of the land use categories. This requires ground truth information in the form of maps and aerial photographs. After examining all the available information such as the display of the centers of resulting clusters, maps, and aerial photographs, one of the following decisions is made for each cluster: (1) The cluster belongs to a specific land use category. (2) It is a mixture of two or more land use categories or the information at hand is not sufficient to label the cluster, i.e., the cluster is either in conflict or inconclusive in nature. (3) The cluster is of no importance or not valid. We assign that cluster to an "other" category (none of the desired land use classes). The ground truth information such as maps and aerial photographs is used to label the clusters in the following manner. From the examination of the computer printout of clustering results, several spatially contiguous areas (each having more than M points) within each cluster are chosen and the corresponding LANDSAT data is brought in registration with maps and aerial photographs. By studying corresponding areas on all available data we make one of three decisions for each cluster as outlined above. We can also use the reverse process, i.e., define some ground truth points or areas on maps and photographs, and transform those points or areas to LANDSAT image coordinates. We can then label the data clusters. The registration procedure of maps, aerial photographs and LANDSAT data will be discussed later.

e. Reclustering. For the points belonging to the second group of clusters, i.e., clusters in conflict or inconclusive, a reclustering step is applied. First, points belonging to this group are selected from the original LANDSAT data; then the clustering algorithm is applied again to those points. The purpose of this reclustering is to more finely subdivide the data in the difficult areas to allow unequivocal labeling of clusters. After reclustering, all the resulting clusters are labeled using the procedures described in Step d, with the only difference that we now try to label all clusters. Clusters which cannot be labeled properly are assigned to the "other" class. However, we expect that very few points will belong to this group. A schematic diagram showing the steps above is given in Figure 1.

f. Geometric Correction and registration of Maps, Aerial Photographs and LANDSAT Data: Geometric correction, using principally a least square geometric correction program requires that a number of control points be obtained from all the sources of data and entered in numerical form into a program. Obtaining such ground control points for LANDSAT data is an important porblem which remains to be solved for the case in which no high quality, high resolution display of LANDSAT data is available. Alphanumeric printouts of portions of raw LANDSAT data which accentuates landform information is being considered as a possible source of ground control points.

4. PILOT STUDY

The operational procedure described above was applied to two watersheds of different size and geographic location; the Trail Creek Watershed in Georgia and the Castro Valley Watershed in California. Here we explain the results to date.

4.1. TRAIL CREEK WATERSHED

The Watershed is located in Clarke County and in the city of Athens, Georgia. It is relatively small, approximately 30 square kilometers and has been further subdivided into 21 subbasins in an HEC study.

Because of the need to establish a basis of comparison on pixel by pixel for our work using satellite data, we proceeded to do a manual classification of the land use in the watershed using NASA Research Aircraft images (Scene ID 6274 000 50047, 74/4/24). The manual classification serves as a principal basis for the verification of remote sensing classification results. Results of the manual classification are displayed in Figure 2. A tabulation of the percentage of each land use class is shown in Table 2.

4.1.1. MAXIMUM LIKELIHOOD CLASSIFICATION

In order to test the suitability of well developed classification algorithms, we first examined a maximum likelihood classifier. A particular version of LARSYS program was chosen primarily because of its availability and because of the well established application of maximum likelihood classifiers in agricultural land use classification [4].

We have attempted to classify an October scene (Scene ID 8180415322, 74/10/5) of the LANDSAT image of the Trail Creek Watershed using a maximum likelihood classifier. The steps in the classification procedure are: (1) Define a reasonable set of land use categories, (2) locate one or several training fields for each class on LANDSAT imagery and identify the coordinates of each training field, (3) run the classification program, and (4) process the result for display and tabulation. The classification result is displayed in Figure 3 and summarized in Table 2, along with other results.

4.1.2. CLUSTERING APPROACH

As explained previously, we encountered difficulties in the use of the maximum likelihood classifier, such as the choice of land use categories and defining training areas.

Considering these difficulties and our objective to develop an operational procedure with a minimum amount of interaction, we shifted emphasis from supervised to unsupervised classifiers. The clustering approach to land use classification is based on classifying first the data into machine classes or clusters according to machine measure of homogeneity without injecting into the process the human preconception of what the land use categories should be. Then a human being interacts with the machine to interpret and refine the results of the machine classification. At this second stage, the prior knowledge of land use and the relative importance of achieving accurate classification results for each land use category play an important role.

We have used the clustering approach for the Trail Creek Watershed. The same October scene used in the maximum likelihood classification was used again. The procedure used for our pilot study consists of the following steps:

(1) Principal component transformation of the data. The original LANDSAT image is transformed for data compression using the Karhunen Loeve transformation.

(2) Clustering of the data. The first two components of transformed data KL1 and KL2 are clustered. A display of the centers of resulting clusters are given in Figure 4.

For the purpose of comparison, we tried to label all clusters with land use categories as best we could without using the reclustering step. The result of the classification is summarized in Table 2, and designated "one step clustering."

(3) Initial classification. As described in step d of the operational procedure, we divide the clusters into three groups, shown also in Figure 4.

(4) Reclustering. For the clusters marked "reclustering" in Figure 4, we applied the

clustering program again using a different set of parameters. The final result of steps (3) and (4) are shown in Figure 5 and Table 2.

The result obtained by this operational procedure can be compared to the ground truth and to the maximum likelihood classification result. Even though clustering is significantly better than maximum likelihood classification, improvements might not be as apparent in direct numerical comparison of percentage of land use in each class, since generally numerically compiled results are the average of many detailed effects. However, the following conclusions seem justified.

(a) The clustering approach results in a significant improvement over the maximum likelihood classification when we examine the detailed classification point-by-point on an image.

(b) The clustering approach is much more flexible in the sense that the classes are assigned after the fact.

(c) Reclustering result is a significant improvement over the one step clustering classification.

(d) It still appears to be necessary to devise some kind of consolidation program to remove extraneous and isolated misclassified points.

Note also that we have used finally, only 6 land use categories instead of the 10 categories used by HEC. The following comments are pertinent:

(a) The separation of industrial and commercial classes. These two categories may not be differentiated accurately from remote sensing data. By applying a spatial consolidation algorithm, a partial success appears possible. For example, in clustering, we have a good indication that downtown commercial areas and large size parking spaces around shopping centers may be identified. Further work is needed.

(b) Density of residential areas. That depends largely on the definition of low, medium and high density residential areas. Residential areas, generally, tend to be clustered as newly developed or old residential areas on the basis of surroundings rather than housing density. More work on fairly large urban areas is needed to determine whether density of residential areas can be determined by using remote sensing data.

(c) Separation among agricultural, pasture and developed open space. We have not paid too much attention to this problem as yet. Even with lots of care and attention, it seems difficult to separate these classes even from high-flight images.

4.2. CASTRO VALLEY WATERSHED

Because of our interest in developing techniques useful in all parts of the country and because of the need to firm all details of the procedure, we are working on several watersheds across the United States. We are completing work on the Castro Valley Watershed in the San Francisco Bay Area. The Castro Valley Watershed is very small (12.8 sq. kilometers) and highly urbanized. It has been studied in great detail by the Corps of Engineers. We have applied the operational procedure based on the clustering approach and conducted also classification by photo interpretation using aerial photographs backed up by a ground visit to Castro Valley. On the basis of results to date, we are able to classify this watershed into six different classes and with an accuracy comparable to what was achieved for the Trail Creek Watershed. Shadows are much more pronounced in the Castro Valley Watershed and may result in classification problems.

5. DISCUSSION

We feel that we are developing a technique which should be usable operationally and we are trying to finalize the procedure so that the Corps of Engineers can use it with only line printer output. We are also planning to study in the coming few months 2 to 4 additional watersheds of different sizes (ranging from 250 to 750 square kilometers) and of different terrain across the United States to determine the applicability of the operational procedure to different geographic conditions and to different constraints on availability of data

In order to make the operational procedure complete, there are several remaining problems to be solved. First, we need to improve classification accuracy within urban land use classes.

This problem appears to be difficult to solve perfectly and seems to be the major challenge for future work and possibly for higher resolution sensors. We also expect to encounter problems for large size watersheds in terms of computation time. And last, but not least, we have a continuing problem of compiling the results. In order that the classification based on LANDSAT data be integrated into a Grid Cell Data Bank, the original LANDSAT pixels should be distorted, scaled and resampled. In spite of these remaining difficulties, we are hopeful that the procedure developed will be widely useful in the common situations where specialized interactive computing equipment is not available.

6. REFERENCES

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7. TABLES

1. NATURAL VEGETATION

   Heavy weeds, brush, scrub areas, forest woods

2. DEVELOPED OPEN SPACE

   Lawns, parks, golf courses, cemeteries

3. LOW DENSITY RESIDENTIAL

   Single Family: 1 unit per 1/2 to 3 acres; average 1 unit per 1-1/2 acres. Areal Breakdown: 5% structures; 10% pavement; 50% lawns; 37% vegetation. Proportion developed = 60%

4. MEDIUM DENSITY RESIDENTIAL

   Single Family: typical subdivision lots; 1 unit per 1/5 to 1/2 acres; average 1 unit per 1/3 acre. Areal Breakdown: 10% structure, 15% pavement, 45% lawns, 30% vegetation. Proportion developed = 70%

5. HIGH DENSITY RESIDENTIAL

   Multi-Family: row houses, apartments, townhouses, etc., structures on less than 1/5 acre lots; average 1 unit per 1/8 per acre. Areal Breakdown: 25% structures; 15% pavement; 35% lawns; 25% vegetation. Proportion developed = 100%

6. AGRICULTURAL

   Cultivated land, row crops, small grain, etc.

7. INDUSTRIAL

   Industrial centers and parks, light and heavy industry. Average 1 plant per 8 acres. Areal Breakdown: 20% pavement, 50% structures, 30% open space. Proportion developed = 100%.

8. COMMERCIAL

   Shopping centers and "strip" commercial areas. Average 3 structures per acre. Areal Breakdown: Structures 30%, lawns 5%, vegetation 10%, pavement 55%. Proportion developed = 80%

9. PASTURE

   Livestock grazing areas, ranges, meadows, agricultural open areas, abandoned crop land

10. WATER BODIES

    Lakes, large ponds, major streams, rivers

TABLE I. HEC LAND USE CATEGORIES, TRAIL CREEK WATERSHED

Land Use	Percent of Area: Ground Truth	Maximum Likelihood Classification	One Step Clustering	Operational Procedure
Natural Vegetation	50.17	36.19	48.69	45.06
Residential	(low density) 2.45 (medium density) 6.79 (high density) 0.11	23.78	16.60	15.31
Dev. Open Space	0.49	8.82		
Agricultural	28.73	19.17	26.69	32.24
Pasture	3.04			
Industrial	2.59	6.08	5.84	5.21
Commerical	1.55	1.97		
Water Bodies	0.57	1.02	0.97	0.97
Trailer Parks	2.47	2.98		
Highways	1.06			
Open Space			1.21	1.21

TABLE II. AREAL PERCENTAGE OF LAND USE AS DETERMINED FROM LANDSAT IMAGE - TRAIL CREEK WATERSHED.

8. FIGURES

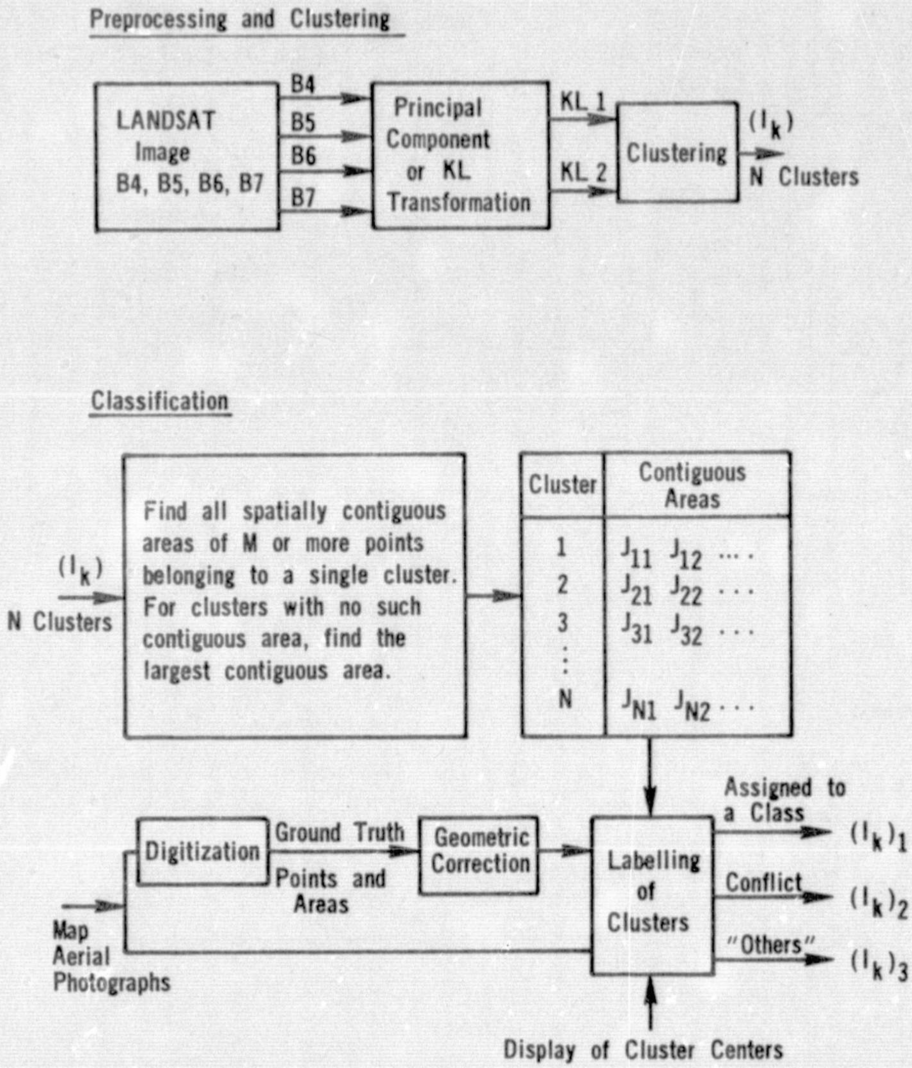

Figure 1. An Operational Procedure for Land Use Classification.

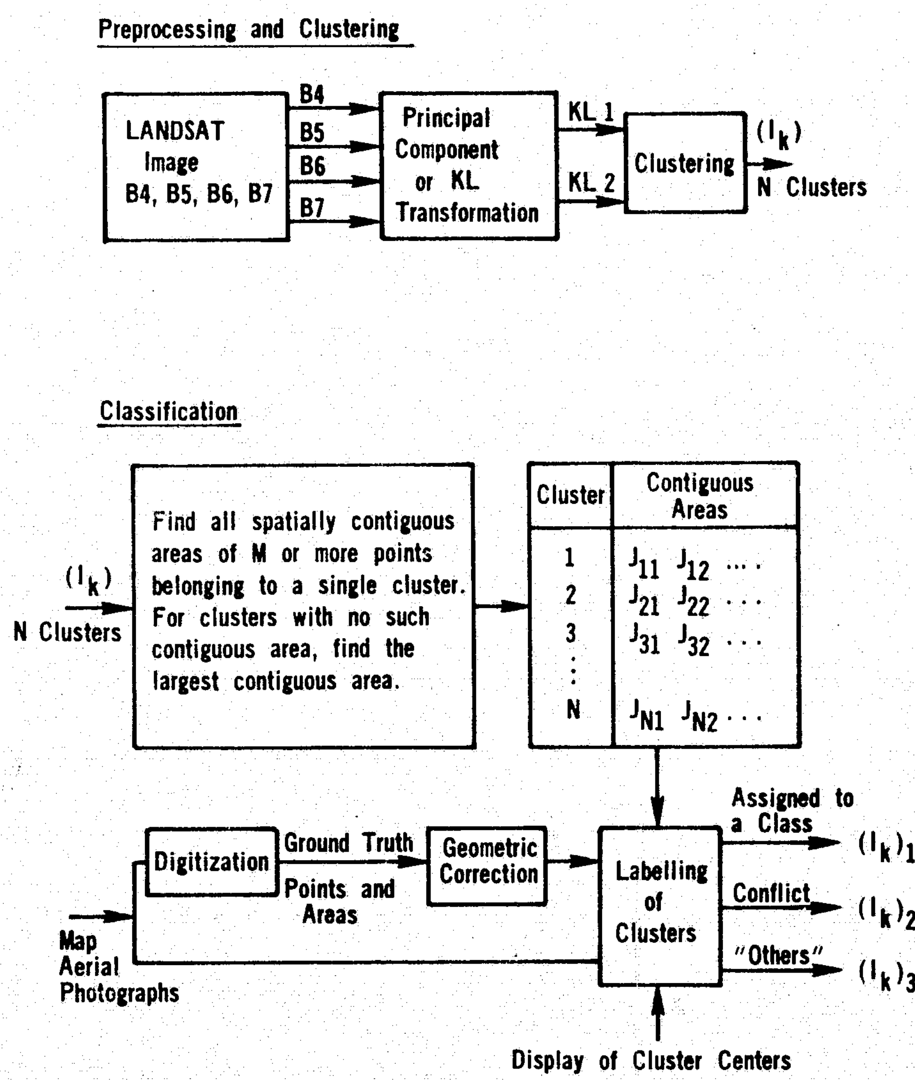

Figure 1. An Operational Procedure for Land Use Classification.

Reclustering

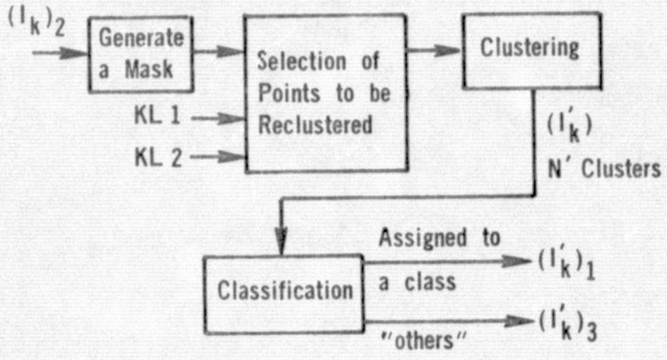

Figure 1. (Cont.)

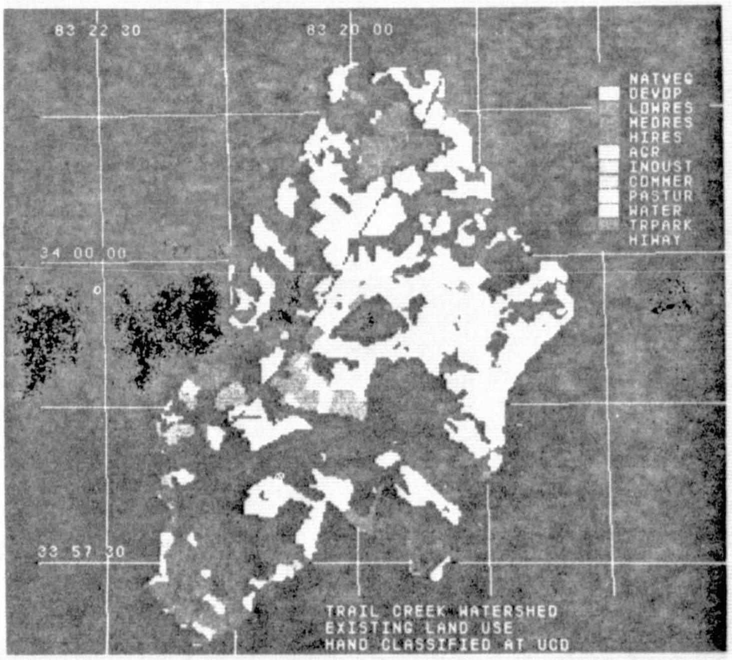

Figure 2. Trail Creek Watershed, Existing Land Use (Ground Truth)

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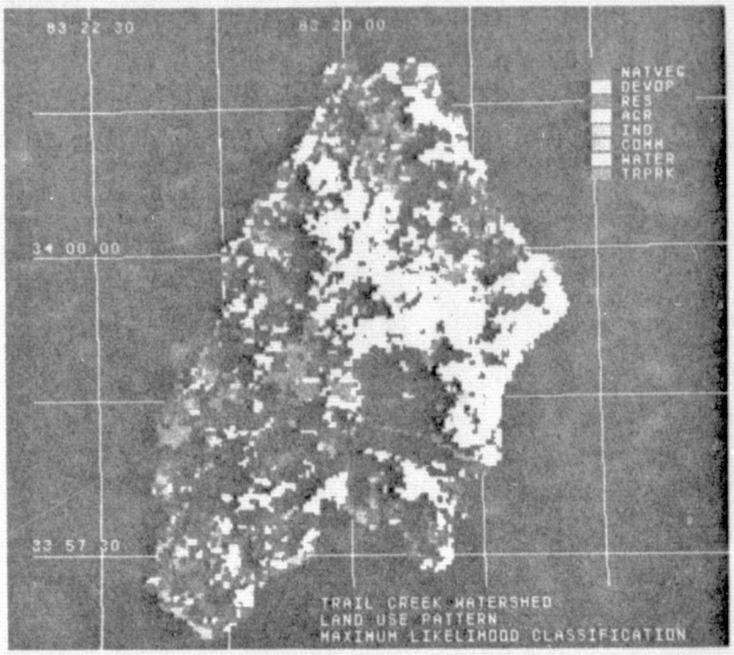

Figure 3. Trail Creek Watershed Land use Pattern, Maximum Likelihood Classifier.

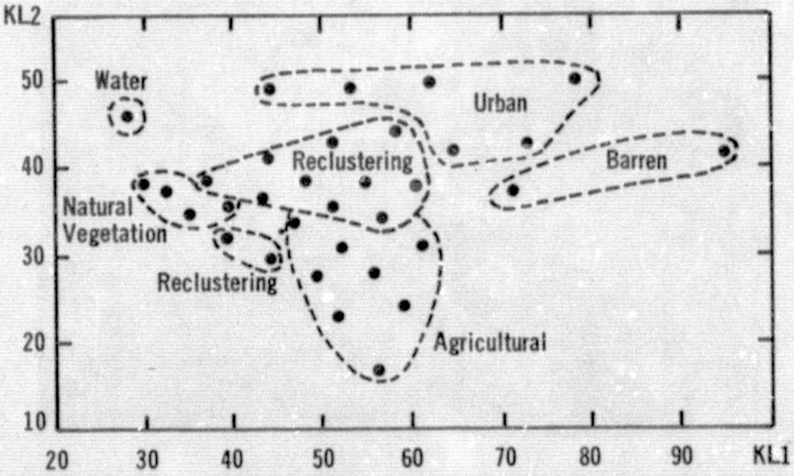

Figure 4. The Cluster Centers and the Initial Decision Made on Each Cluster.

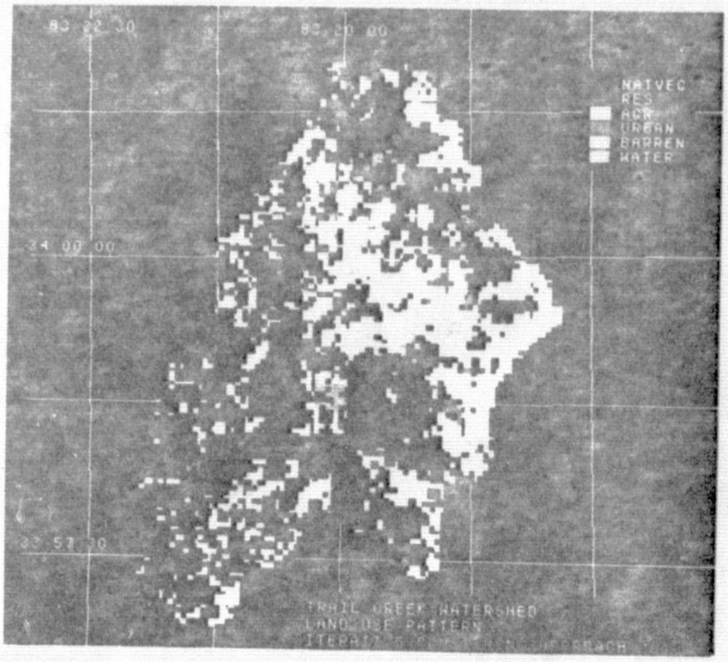

Figure 5. Trail Creek Watershed Land Use Pattern, Operational Procedure.

9. ACKNOWLEDGMENT

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Special Study No. 4

SUMMARY OF OBSERVATIONS ON THE RECENT AIAA-NASA CONFERENCE ON "AEROSPACE TECHNOLOGY TRANSFER TO THE PUBLIC SECTOR"

by

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I. Summary of Observations on Conference

On November 9, 10, 11, 1977, the American Institute of Aeronautics and Astronautics and the National Aeronautics and Space Administration jointly sponsored a conference, "Aerospace Technology Transfer to the Public Sector." The attendees, numbering about 100, represented private corporations, research institutes, universities, and government agencies at various levels, with individuals' participation in working groups based on particular areas of interest. Thus, Communications Technology, Housing and Urban Construction, Health Technology, Natural Resource Planning and Management, and Transportation attracted those persons concerned with aerospace technology applications in those areas. (Incidentally, there was little time or opportunity for session-hopping; whatever cross-fertilization that occurred came from the several plenary sessions, where the interim and final reports presented by group leaders probably reflected their ability as communicators and their perspective and bias more than the actual content and discussion.)

This account, based on participation in only one such group, namely, Natural Resource Planning and Management, does not presume to summarize the entire conference. However, I can provide a fairly useful overview by combining my own notes and observations with the official documentation, such as pre-Conference working papers, session summaries, and post-Conference communications.

The November 23, 1977 "Summary of Principal Findings and Recommendations" contained the following paragraph:

> This Conference reviewed the potential, the mechanisms, and the results of the technology transfer process by (a) assessing the results of technology transfer on a number of public sector service areas; (b) reviewing the primary barriers which are currently impeding the aerospace technology transfer process; and (c) identifying appropriate courses of action, both by the private sector and by all levels of government, to enhance public-sector utilization of aerospace technology in the technology areas.

One immediately observes not only redundancy between this post-Conference Summary and the pre-Conference statement of Scope but actual verbatim repetition. This circularity, while recognizable as the conventional rhetoric accompanying such events does, nonetheless, have portent. It indicates the

closed-loop nature of the conference format and the cynical view that nothing significant can or will result from the conference. Such an attitude is deplorable since by its inherent self-fulfilling prophecy, it virtually precludes useful outcomes and effectively excludes the insights that may have been generated through discussion. The complete congruence between stated aims and achievements does not imply complete success; rather, it imparts a *deja vu* quality that deprives the conference of values it might have attained.

With platitudes at the outset and as the outcome, conferences of this kind exhibit serious deficiencies as (a) a worthwhile source of new ideas and (b) a promising mechanism for learning about technology transfer. As to the former, the controversial issues studiously avoided were those which may have been most significant in the transfer process: the questions that were dismissed because there were no easy answers might, if explored further, have contributed more understanding than did discussion of formal agenda items. As to the latter, recalcitrant determination to remain low on the learning curve was amply demonstrated by the failure to heed the wise words and comments of Dr. Robert A. Frosch in his keynote address. Indeed, the Conference proceeded as though the opening session had never taken place!

Dr. Frosch's parting appeal for "complexifiers" as an antidote to Washington's plethora of "simplifiers" fell on deaf ears. As is usually the case, Conference language had the subject writ large and the predicate small -- a sure formula for simplistic thinking. As a consequence, official descriptions, fore and aft, were not only simplistic but unthinking as to logical inference. To equate the *potential* of *the technology transfer process* to the program's *assessment* of the results of technology transfer "in a number (6) of different public-sector service areas" was to harness a powerful Percheron to a little red wagon. The "results" of technology transfer are often illusive, incalculable, and immeasurable, often difficult to pinpoint, and probably debatable as to impact. To presume that such results as were covered by the Conference adequately reflected the *potential* was to skew and so limit the focus as to confine aerospace technology in perpetuity to the near reduction to absurdity of ceramic pipe bowls and slippery water!

Significant transfers to "public-sector service areas" are just beginning to occur. Not only is assessment of results premature, therefore, but, the mandate imposed by OMB and other budgetary watch dogs to demonstrate early cost/effectiveness appears to constitute one of the most serious barriers to technology transfer. This is particularly true in the case of state and local agencies, which operate in a precarious political environment. Forced to justify expenditures before benefits can be properly harvested,

officials are inclined to extreme conservatism. And the usual cost/benefit calculations would support this position, since they cannot accomodate uncertainty and unknowns. Where benefits are diffuse and/or long in materializing, innovators are forced to quantify pie-in-the-sky, perform methodological miracles, or forego innovation as too risky. On this matter, Dr. Frosch's observations were particularly germane: economists' tools of analysis do not fit; their models cannot cope with future technologies. Since human life is not tidy and no one can predict the future, much of what passes for forecasting is mythology. Instead of regarding technology transfer as solutions looking for problems, we might fruitfully entertain the possibility that available new technologies provide a redefinition of problems so that they become tractable.

Unfortunately, Dr. Frosch's contributions to the Conference have not been mentioned in the documents. Thus, lost are his views on the dynamics of the process of technology transfer, the time element, the people factor, the opposition and difficulties faced by NASA, and the international implications. Instead, the "findings" purportedly distilled from review of the six specific applications clustered about the following points:

(1) Person-to-person communications is the optimum transfer medium. There must be mutual understanding between technical and user communities.
(2) "The major impediment to effective technology transfer is the lack of adequate funds to carry out the necessary educational and evaluation processes which precede implementation."*
(3) Successful instances of aerospace technology transfer to the public sector should be widely publicized by the public-sector beneficiaries as leverage for promotion of a National Policy (see item 5 sotto).
(4) Private industry, perhaps better than state and local government, can serve as a medium of technology transfer, with engineers playing a key role.
(5) Clearly needed is a National Policy on Technology Transfer, to be articulated and formalized by executive order as well as supported "at adequate funding levels." Such policy would properly include, first, "effective formalized utilization of the well-developed disciplines of systems analysis, in addition to the utilization of specific products" and, second, a combination of "existing -- sometimes rather mundane" -- as well as new "exotic" technologies as "elements in the transfer process."

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* This item is quoted verbatim and in its entirety as an example of the large subject-small predicate format that deteriorates into meaningless platitude.

One might assume, to judge from the emphasis on and amount of space devoted to the recommendation for a bureaucratic network dedicated to the dissemination of aerospace technology, that item (5) emanated from Conference deliberations. This, so far as I can ascertain from review of the respective working sessions, was not generally the case although the Communications Working Group had included in its list of missing links in the transfer process a centralized government unit. One can conclude, therefore, that the architects of the conference used the occasion as the vehicle on which to launch this proposal, which displays an astonishing degree of ignorance about the working of the bureaucratic world as well as an appalling ignorance of the state-of-the-art of systems analysis as a viable article for export.[1]

Since official documentation of the Conference has contained no reference to the contribution of William Donaldson, City Manager of Cincinnati, I deem it proper to accord honorable mention to his views because of their down-to-earth good sense. His emperor's-new-clothes assessment of technology transfer was an interesting complement to Dr. Frosch's remarks -- and was similarly ignored! Describing as "disproportionately small" in comparison to the investment the results of technology transfer, he found the effect of applied science on local government service delivery systems to be disappointing and asked _why_. "Most of the conferences that have dealt with technology transfer have spent their time in examining the technologies that might be useful and the mechanism that might be used to adapt them to local government. Very few have spent very much time talking about the problems of how you get the horse to drink." He recommended that the technical experts redirect their energies from the _what_-to-do to the _how_-to-do-it.

II. Specific Aerospace Technology Applications

Communications Technology

In the context of the Post-Industrial Era, as envisioned by Daniel Bell,[2] advanced technologies related to transportation and communications have brought men into close contact, bound them in new ways, and made them more dependent on one another for specialized services. Central to the rise and development of the service economy is information, the acquisition, processing, storage, interpretation, and utilization of which are

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1 Robert A. Frosch, "A New Look at Systems Engineering," _IEEE Spectrum_, September, 1969, pp. 24-28.
Ida R. Hoos, _Systems Analysis in Public Policy: A Critique_, University of California Press, Berkeley, 1972.

2 Daniel Bell, _The Coming of Post-Industrial Society_, Basic Books, Inc., New York, 1973.

accomplished through modern communications technologies. Here, NASA's contributions are significant. However, transfer of space-derived know-how to urban communications needs at state and local levels does not occur without travail. Not only is ignorance an obstacle but also the lack of two vital elements, viz., effective receptors at the user end and, as mentioned earlier, a government unit to act as transfer agent. The Communications Working Group's summary statement attempted to set forth guidelines for overcoming "obstacles to the transfer of communications technology to state/local government users and to effectuate the technology transfer process." For this, they recommend that "a mechanism" be set up "to permit" state and local governments "to establish a pre-defined quantitative scale to evaluate level of success".

While some of the above conclusions suggest recognition of the real-life complexities of adapting Space Age communications to state and local usage <u>and</u> getting the latter to adopt them, the imposition of a quantitative measure of success assures almost certain abortion of the effort. In most observed cases of improved information handling and transmission, quantifiable results are not only elusive but relatively unimportant as an index to societal benefit, especially in the long run. The injunction "to establish a pre-defined quantitative scale to evaluate level of success" is an egregious flying-in-the-face of Dr. Frosch's charge to the Conference.

Housing and Urban Construction

Of interest here were the ways in which NASA technology could be useful in the field of housing and urban construction. Examples included (a) NASA involvement with ERDA in solar heating and cooling demonstrations, and (b) aerospace companies' products and services related to fire equipment, solar energy components, and the like. Obstacles to the technology transfer seemed to be largely institutional, e.g., archaic building codes, recalcitrant union regulations, and rigid insurance standards. Stressed here as elsewhere was the importance of the user community, embracing not only government officials at all levels but consumer protection and regulatory groups. In this area, as in most of the others, the "proper and appropriate role" for the federal government was "to stimulate innovation and provide 'front' money."

Health Technology

Dr. James N. Brown, Jr. of the Research Triangle Institute, carefully delimited the focus in the complex and diffuse area of medical technology. After making the excellent point that most significant technological transfers to medical research usually require long periods of time to realize a beneficial impact on the practice of

medicine, he chose "those transfer opportunities and situations involving widespread utilization" or, in other words, those transfers seen to benefit medical diagnosis and treatment in a significant sector of medicine. Among the instances of medical technology transfer were the following: (a) small computer capability; (b) patient isolation garments; (c) multispectral photographic analysis of burn injury; (d) controlled rates of freezing biological fluids and tissues; (e) geometric configuration of coronary tree; (f) Temperfoam (an open-cell polyurethane silicone plastic foam especially designed to cushion severe impacts and, therefore, useful in airplane seats, football helmets, and the like); (g) compact blood analysis systems; (h) rechargeable cardiac pacemakers; (i) servo-controlled infrared optometer, a device that automatically measures the refractive error of the eye, prints out the proper prescription for glasses, and detects cataracts; (j) a hand therapy device.

By far the most useful contribution to the Conference came in the form of Dr. Brown's working paper. The summary that appeared in the stultifying bullet-format lost all of the depth of perception and provided so sterile a view that little was communicated of its message or of the essence of the sessions. Instead, such inanities as the following constituted the introduction to the summary:

> Transfer of health technology can be enhanced by (a) stimulating more opportunities for innovation, and (b) eliminating or reducing the many barriers to industrial participation in the transfer process.

Recommendations embodied in the rest of the statement reflected the familiar set of hoary canons, i.e., the pitch for "system concept studies," the plug for cost/benefit analyses. The emphasis on an institutional mechanism, such as a "National Health Technology Ad Hoc Advisory Panel" with a cadre of technology transfer agents, seemed to be less an outcome of the discussions and more a manifestation of what might have been the hidden agenda of the convention's architects.

Transportation

The distance between the areas of concern voiced in the pre-Conference working paper of John B. Crosseto, Jr. and those which were highlighted in the summary is notable. The earlier document had listed a number of examples of successful transfer of aerospace technology to elements of public transportation. Integrated circuitry, light-weight structures, and improved lubricants were cited in this connection. Mr. Crosetto acknowledged, however, that "the record of technology transfer at system level applications is less than spectacular. Several large, modern urban transportation systems have been plagued with problems that have received a high degree of public exposure and criticism."

Since the Bay Area Rapid Transit (BART) system and others like it are manifestations of over-enthusiasm for Space Age concepts where an application of horse sense might have been more apropos, Crosetto's statement gave promise of some much-needed critical analysis. If this occurred during the sessions, no word of it slipped into the final report, which embraced all the cliches, promoted the "National Technology Transfer Policy", and generally proceeded on the cavalier assumption that the only problems in the transfer of aerospace technology to urban transit were lack of money and a mechanism for attracting and funneling the money! If the panelists ever responded to their chairman's request to examine the process of technology transfer and to try to identify the different characteristics for success at the component, process, or system level, the benefits of that experience were not shared through the watered-down, over-generalized, propaganda-ridden summary.

Natural Resource Planning and Management

The working paper for this section provided a brief historical background of remote sensing, from the Apollo-Gemini era to the current generation of Landsat Five applications were described in detail: The Texas Natural Resources Information Systems, the Mississippi Demonstration Project, the Georgia Digital STatewide Processing Program, The North Dakota Regional Environmental Assessment Program, and the South Dakota Land Resource Information System. The chairman of the group, Paul A. Tessar, drew up a list of problems as he perceived them. Attributed to NASA were the following: (a) over-selling of the technology; (b) lack of an overall strategy and a coordinated, organized approach to technology transfer; (c) too much reliance on the approach of using universities to transfer technology to state governments; (d) a preference for working with technologists rather than decision-makers; (e) inadequate staff and financial resources to complete the transfer effort; (f) shortage of formal state imput to Landsat mission and policy planning activities; (g) lack of a permanent operational satellite system and (h) problems with the current data distribution system.

As for problems encountered in the states, the following were listed: (1) fragmentation of natural resource responsibilities among many agencies with differing viewpoints, needs, and resources to address them; (2) shortage of financial resources and expertise to adequately support technological activities; (3) lack of thorough natural resource information needs identification and analysis; (4) bureaucratic unwillingness to invest in develcping new capabilities; (5) lack of a unified voice to represent state and local needs in Landsat mission planning; and (6) inadequacy of communication between and within states.

In the view of Mr. Tessar, lack of state representation on the Federal Coordinating Committee in Landsat seemed to be the main problem. The states, he averred, need "to speak with one voice for themselves." That this was not a conclusion on which the natural resource planning and management working group had reached consensus, or one that was even discussed at length, points up again the distance between intent and content in this Conference. That this item should appear as one of the three specific recommendations purportedly emanating from the sessions may be explained by the sentence, "NCSL would be happy to coordinate such a group."*

Review of my notes taken at the actual working sessions indicates that the breadth of concerns was not limited by the scope of the section chairman's pre-Conference working paper, which had "Land Use Planning" as its title. At a very early point, trenchant questions were raised as to the transfer process: how do we get technologies to the users? when can the technologies ultimately benefit? where and of what sort are the mechanisms to implement the transfer? what are the conditions for transfer? The discussion ranged wide. Some attention was paid to the need to discriminate among resource questions amenable to treatment via Landsat, those where other satellite technology might be advantageous, and those which fall outside the purlieu of technology. Here, the political, economic, bureaucratic, jurisdictional, legal, and social aspects of resource management decisions brought forth a lively exchange of ideas. Along with the possibility that satellite technology might offer a viable means of circumventing traditional legal and jurisdictional barriers, there was recognition that herein might also be the makings of new battle formations. If, as was proposed, coordination of function between the U.S. Coast Guard and the U.S. Department of Transportation was requisite for proper funneling and collation of data from Seasat, then a new level of synergy was a <u>sine</u> <u>qua</u> <u>non</u>. However, with <u>autonomy</u> and <u>control</u> two main pillars of organization, the prospect of such cooperative effort seemed ephemeral in the extreme.

When in this connection, the OSTP** was brought up as a possible agency for fostering technology transfer, inadequacy of budget posed an immediate obstacle. While the OSTP is in the process of trying to develop programs, its efforts are perforce spread thin. Earlier efforts to move technology to the state and local levels having been virtually eliminated by an Office of Management and Budget edict against advisory panels, this link has not been established. Inherent in the discussion

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* NCSL, of which Mr. Tessar is assistant director of the Remote Sensing Project, is the National Conference of State Legislatures, an organization designed to strengthen the role of state government in relation to federal program and policy.

**Office of Science and Technology Policy.

was the bothersome question: who will pay? and the related question of how do you assess value? The OMB requires firm numbers. But these are unavailable within the short term of the budgetary time cycle and may be unattainable even in the longer term. Their lack does not make the effort less valuable. It may, in fact, be all the more so, but failure to produce "hard" evidence can foreclose the whole endeavor. This requirement for premature proof of worth has been observed in many areas where technological advance needs support and encouragement, to stand as an insuperable stumbling block.* At the state level especially, some technologies show promise of delivering economies but immediate cost calculations cannot reflect them. Possible only in life-cycle terms, such estimates carry no weight in legislative circles, where the political environment has its own special life cycle. An axiom emerges here: the technological time frame is often greater than that in which the political entity has to operate and artificial accomodation between them becomes a Procrustean** task. The injunction to supply economic justification too early has led to much frenetic and some frantic figure-manipulation. The self-defeat of the cost/benefit analysis is embarrassingly visible in the Science[3] account of the study done by Chase Econometric Associates to demonstrate the direct connection between investment in NASA research and the U.S. gross national product. The extravagant claims were challenged by Senator Proxmire, who asked the General Accounting Office (GAO) to perform a critical analysis. Their review[4] stated that not only did the Chase study fail to prove that the economic benefits were of the magnitude calculated but that "plausible and minor changes" in the methods used could lead to dramatically different, and probably devastating, conclusions. In describing the Chase study as "more fiction than fact", Senator Proxmire was, if not indicting, at least calling to account the very management tools in vogue at all levels of government. In the final analysis, credibility turns out to be the name of the game; much depends on whose numbers one is willing to believe. Perhaps, now that this realization has penetrated the halls of Congress, it will percolate to the OMB. At that time the slavish performance of the cost/benefit ritual will be recognized as the artifactual numbers game it is, its resemblance to the real-life dimensions of technology assessment largely coincidental.

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* In the development of the electric vehicle, for example, I recently commented that "cost is the cart put before the technological horse."

** Procrustes, a mythological innkeeper, seized travelers and tied them to an iron bedsted, into which he forced them to fit by either stretching them or by cutting off protruding members.

3 R. Jeffrey Smith, "NASA Study Was Bust, Not Boost, Says Proxmire," Science, 25 November 1977, pp. 810-811.

4 Comptroller General of the United States, "NASA Report May Overstate the Economic Benefits of REsearch and Development Spending," General Accounting Office, PAD-77-18, October 18, 1977.

Because decisions about adopting technology and calculations of impacts, advantageous and adverse, must ultimately be made in the social and political environment, this is the aspect of the transfer process that requires most careful handling. And so far it is one which has attracted least attention. The facile hidden assumption of the Conference management seemed to be that once technical feasibility has been demonstrated, transfer automatically follows -- or will, given the ministration of the super-coordinating transfer agency! No such fantasy prevailed during the discussions. Mrs. Judith C. Toth, a member of the Maryland General Assembly, contributed an enlightened and pragmatic view of legislators' perceptions of and reactions to high technology. In a subsequent exchange of correspondence, J.J. Duga, of Battelle's Science Policy and Technology Transfer Programs, added a succinct postscript to the deliberations. Deploring the over-simplistic views of purveyors of hardware and software, especially when they find themselves in the realm of political decision-making and value judgments, he wrote[5]:

> State and local governments -- regardless of how well equipped they might be to understand and assimilate technology -- have changing needs and priorities; they have to make extremely difficult choices between alternate courses of action; they have limited resources that must be carefully husbanded; and they have political accountability to a constituency which is often unsympathetic with even the most basic concept of compromise.

Since the official working paper which was supposed to structure the discussion concentrated on the what rather than the how of the specific instances, it followed the well-trodden path of concern with product rather than process. Consequently, discussion of these vital points came through disjointedly as discrete observations, as participants succeeded in gaining the floor in a sequence dictated by turn rather than by coherence. Unfortunately, a disproportionate amount of time had to be devoted to debate over and redrafting an item intimating that universities had been relied on too heavily in the transfer of remote-sensing to state governments. Some of the "problems" attributed to NASA could and should have been disputed; this one, incorrect historically and potentially damaging, demanded attention lest it slip into the permanent record as though emanating from the Group.

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[5] J.J. Duga (Science Policy and Technology Transfer Programs, Battelle Columbus Laboratories), personal letter to Ida R. Hoos, December 12, 1977.

Unaccountably absent from the agenda of both Conference and the Pacific Northwest Land Resources Inventory Demonstration Project (known as the PNW Project). Spanning three states, Oregon, Washington, and Idaho, involving nearly thirty agencies concerned with resource planning and management, linking the technically and administratively competent NASA staff with state and local users, this Project could have provided an enormously valuable background against which to address the real-life dimensions of technology transfer. The PNW Project, now entering its final phases, is a unique example of careful organization, calibration, and management. In its exploration of applications of remote-sensing techniques in forestry, agriculture, rangeland, and urban development, the Project encountered the full gamut of responses familiar to those who would introduce change. This innovative experiment represents a landmark, well worth analysis and review, since it contains most, if not all, of the elements necessary in effecting a transfer of aerospace technology to resource management. So as to attain as full an understanding as possible of the dynamics of the process, the project director at NASA-Ames encouraged and made provision for exploration of its social dimensions. The documentation and analysis now underway will provide a rich reservoir of experience upon which to draw as the Regional Applications Program translates the technology of space to mankind's home-based problems.

The concept of technology transfer is not new. Literature on the subject covers the past quarter of a century. Interesting and provocative experimentation, such as exemplified by the PNW Project, already provides a wealth of important information. Candid review of the AIAA-NASA conference on Aerospace Technology Transfer in the Public Sector points to the ineluctable conclusion that such meetings, judged on the basis of effectiveness as a medium for communication and enlightenment, would not be worth the cost!

Chapter 8

SUMMARY

Robert N. Colwell

Chapter 8

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Robert N. Colwell

As emphasized in Chapter 1 of this progress report, our multi-campus group is now concentrating on the preparation of procedural manuals that deal with applications of remote sensing to an area's entire "resource complex", including its vegetation, soils, geology and water resources. These manuals are being prepared: (1) in both abridged and unabridged versions, the latter providing much more complete descriptions and documentation than the former, and (2) in degrees of aggregation ranging from a single aspect per manual to all aspects. In order to maximize the prospect that these manuals will be comprehensible and usable, our multi-campus group has continued to maintain close liaison with the personnel of such potential user agencies as (1) the U.S. Forest Service; (2) the California Department of Water Resources; (3) the Bureau of Land Management; and (4) various county governments and private industrial groups.

In Chapter 2, a report is given of water supply studies that are being performed by the Davis campus group. The contents of that chapter reflect the orderly transition that has been occurring during the past year (with NASA approval) as the Davis campus team has been bringing to a close its studies as funded under this NASA grant, and transferring its remote sensing-related activities to follow-on programs of the "ASVT" type under separate funding. Thus their redirected efforts represent a logical step toward bringing about the acceptance of modern remote sensing techniques by various user agencies, especially those techniques dealing with the estimating of water supply.

Chapter 3 describes work that has been performed during the present reporting period by personnel of the Remote Sensing Research Program on the Berkeley campus. As previously mentioned, the emphasis is very largely on the preparation of procedural manuals. Hence, Chapter 3 includes the following items:

(1) An updated procedural manual titled "Remote Sensing as an Aid in Determining the Areal Extent of Snow";

(2) "Remote Sensing as an Aid in Determining the Water Content of Snow";

(3) the outline for a procedural manual titled "Remote Sensing as an Aid in Watershed-wide Estimation of Water Loss to the Atmosphere";

(4) the outline for a procedural manual titled "Remote Sensing as an Aid in Watershed-wide Estimation of Solar Radiation"; and

(5) the outline for a project that continues to be actively pursued that will lead to the production by 30 April 1979, of a procedural manual titled "Remote Sensing as an Aid to the Inventory and Management of an Area's Multiple Resource Complex".

In addition, Chapter 3 provides a report on work done by personnel of the Remote Sensing Research Program relative to (1) Watershed Boundary Determination; (2) Geometric Correction of Landsat Data for Watersheds; (3) Vegetation/Terrain Analysis of Watersheds; and (4) the Collection and Analysis of both Ground Climatic Data and NOAA-4 Satellite Data for Watersheds.

Chapter 4 consists of an account of work done during the present reporting period by personnel of the Geography Remote Sensing Unit (GRSU) on the Santa Barbara Campus of the University of California. Most of that work is an outgrowth of the remote sensing-related water demand studies which that group has been performing in the San Joaquin Valley and other parts of central California during the past several years. Their efforts are now being concentrated on the preparation of a Procedural Manual for use in developing a Geo-base Information System. To ensure that this work would be of practical value, personnel of the GRSU have worked closely with resource-related agencies and officials in Ventura County, California.

In developing this Procedural Manual GRSU personnel have placed major emphasis on learning about the resource information needs at County level. Then, building on their previous work, they have sought to determine the extent to which a meaningful Land Cover Classification for use in Ventura County could be made from an analysis of remote sensing data as acquired by the Landsat Multispectral scanner. Recognizing the ready availability of information about topography and other terrain characteristics (e.g., through the use of DMATC Digital Terrain Tapes), they have then demonstrated how that information could be merged with the Landsat-derived land cover information.

As a practical use of the merged data, consideration is given in Chapter 4 to methods of identifying various wildlife habitat zones by interrogating these registered sets of data. The chapter concludes with a detailing of the stepwise procedure that should be followed in developing a Geo Base Information System that will be of maximum use at the county level.

In Chapter 5 of this Progress Report, two major topics are dealt with by the Remote Sensing Group on the Riverside campus. Both of these topics are outgrowths of studies which that group has made during the past several years on uses that can be made of remote sensing in estimating water demand.

The first of these topics deals with techniques for mapping land use from remotely sensed imagery. Several months ago these techniques served as the basis for a Procedural Manual which was prepared in preliminary draft form and which has since been submitted to a potential user agency, viz. the Los Angeles Division of the California Department of Water Resources. While general reaction to the Procedural Manual was quite favorable, there was a concensus that:

(1) it is not sufficiently detailed;

(2) in some portions of it the procedures to be followed need to be expressed more clearly, and

(3) the time required and associate costs incurred for each of the various procedural steps should be documented.

Each of these suggestions is eliciting a positive response by the Riverside group. For example, in the present Progress Report, the time requirements and production costs are reported, in one representative instance, for each of the seven steps entailed in producing a land use map by means of computer techniques.

The second major topic dealt with by the Riverside group in this Progress Report is a Spatial Information Processing System. As part of the Riverside group's efforts under this NASA grant during the past several months, that system has been steadily evolving and is now almost fully developed. The system consists of a suite of related computer programs which can be used to perform selected tasks with respect to processing information about the natural resources of an area. Since much of that information is derived through remote sensing, the development of this Spatial Information Processing System (SIPS) has become a vital part of this "integrated study". As specific evidence of this fact, the present Progress Report describes in considerable detail how SIPS can be advantageously used in relation to four major tasks of concern to the resource manager: (1) Map Data Encoding; (2) Geographic Data Base Creation; (3) The Production of Graphic Output in the Form of Computer-Generated Maps; and (4) Data Structure Conversion.

Based on this work the Riverside group is in the process of preparing a Procedural Manual dealing with the computerization of remote sensing-derived information and related data on land use for inclusion in its 30 April 1978 report.

In Chapter 6 the Social Sciences Group on the Berkeley campus reports on its efforts during the present reporting period relative to the transferring of remote sensing technology to resource management agencies in California. Those efforts have resulted primarily in analysis of the following:

(1) the remote sensing-based technology itself, dealing with it both as an entity and in its various manifestations;

(2) the "user community" which is a term that has been stretched to include both real and "ideal" users of modern remote sensing technology;

(3) the factors which can either implement or impede the dissemination, adoption, and application of remote sensing information; and

(4) the methodology of evaluation and assessment that might best be applied when seeking to measure the degree of acceptance of modern remote sensing technolgy.

As in our previous progress reports we have included herewith a chapter (Chapter 7), dealing with "Special Studies". In each instance, these Special Studies have pertained to work that is closely related to that which we are performing under the grant, but not fitting directly under the grant's overall title of "an integrated study of earth resources". Four such special studies are reported upon in Chapter 7 of the present report, VIZ:

(1) "Considerations in the Development of a Decision-Oriented Resource Information System, Incorporating Remotely Sensed Data in Ventura County, California."

It was performed by personnel of the Geography Remote Sensing Unit on the Santa Barbara Campus. As detailed in Chapter 7, this Special Study analyzes the various considerations that enter into the development of a Resource Information System. These inlcude:

(a) Responsibilities of Resources Manangement Agencies,
(b) Informational Requirements on these Agencies, and
(c) Land Classification Schemes that can both Satisfy these Requirements and Lend Themselves to the Use of Remote Sensing.

Types of features studied by the GRSU (using Ventura County, California, as the test site) included the following: Agricultural, Urban, Transportation, Plant Communities, Physiography, and Climate. This Special Study concludes with:

(a) A description of the Developing County System,
(b) the data categories found most useful,
(c) some considerations in data interrogation and analysis, and
(d) requirements with respect to technical support, education and training.

(2) The second Special Study appearing in Chapter 7 is titled "Remote Sensing as a Demonstration of Applied Physics". It constitutes a ten-page abstract of a much lengthier paper that has been prepared by R.N. Colwell, the Principal Investigator for the present NASA Grant, on invitation from the American Physical Society. The full paper is to be presented on 25 January 1978 at the joint national meeting of that Society with the American Association of Physics Teachers. The paper considers the basic principles of physics for which practical applications are found in each of four remote sensing-related areas, VIZ

(a) remote sensing platforms,
(b) remote sensing devices,
(c) the analysis of remote sensing data by humans, and
(d) the analysis of remote sensing data by machines.

The point is made that the field of remote sensing not only has great popular appeal but also great appeal as a topic for classroom discussion. Hence, material contained in the paper should be of considerable interes to both the teachers of physics and their students. Such material, and especially the many specific remote sensing-related ecamples that are given in the paper should provide a physics teacher with some of the better answers that might be given to those commendably demanding students who are inclined to ask, at the end of each classroom session, "so what?". Many of the examples used pertain to NASA's Landsat system and to information which our group, under the present NASA grant, has been deriving from Landsat-acquired data relative to the earth's natural resources.

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(3) The third Special Study appearing in Chapter 7 is titled "Satellite Land Use Acquisition and Applications to Hydrologic Planning Models". It summarizes work done during the past several years, much of it under the present NASA grant, by Dr. Ralph Algazi and his associates on the Davis Campus of the University of California. The paper was prepared for presentation at an international symposium on remote sensing and already has commanded a great deal of interest.

(4) The fourth and final Special Study appearing in Chapter 7 of this grant report deals with certain activities of yet another of our grant participants, Dr. Ida Hoos of the Berkeley Campus. Her special study is titled: "Summary of Observations on the Recent AIAA-NASA Conference on 'Aerospace Technology Transfer to the Public Sector' ".

Among the specific aerospace technology applications considered in this analysis by Dr. Hoos are:

(a) communication technology,
(b) housing and urban construction,
(c) health technolgy,
(d) transportation, and
(e) natural resource planning and management.